PA NT COOPERATION TREAT

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 15 May 2001 (15.05.01)	
International application No. PCT/JP99/03701	**Applicant's or agent's file reference** F0063-LAM
International filing date (day/month/year) 08 July 1999 (08.07.99)	**Priority date** (day/month/year)
Applicant NAKAJIMA, Shu et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   01 February 2001 (01.02.01)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer R. Forax Telephone No.: (41-22) 338.83.38

10/030592

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference F0063-LAM	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/JP99/03701	International filing date *(day/month/year)* 08/07/1999	Priority date *(day/month/year)* 08/07/1999
International Patent Classification (IPC) or national classification and IPC H01L21/68		
Applicant LAM RESEARCH CORPORATION et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand 01/02/2001	Date of completion of this report 15.10.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Mahr v.Staszewski,G. Telephone No. +49 89 2399 2279

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/JP99/03701

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
   Description, pages:

   1-16 as originally filed

   Claims, No.:

   1-8 as originally filed

   Drawings, sheets:

   1/6-6/6 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).

   ☐ the language of publication of the international application (under Rule 48.3(b)).

   ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:

   ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	
	No:	Claims	1
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-3,7-8
Industrial applicability (IA)	Yes:	Claims	1-8
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Reference is made to the following documents:

   D1: EP-A-0 805 487 (APPLIED MATERIALS INC) 5 November 1997 (1997-11-05)

   D2: PATENT ABSTRACTS OF JAPAN vol. 017, no. 247 (C-1059), 18 May 1993 (1993-05-18) & JP 04 371579 A (ULVAC JAPAN LTD), 24 December 1992 (1992-12-24) -& JP 04 371579 A (ULVAC JAPAN LTD) 24 December 1992 (1992-12-24)

2. The present application does not meet the requirements of Article 33(1) PCT, because the subject-matter of claim 1 is not new in the sense of Article 33(2) PCT.

   In fact, all the features defined in claim 1 are anticipated by the teaching provided by D1 (cf. columns 10-12).

   Furthermore, it would appear that the subject-matter of claim 1 is not novel either having regard to the disclosure in D2 (cf. figures 1, 3, 11 and 12).

3. Document D1, which is considered to represent the most relevant state of the art, discloses (cf. columns 10-12) a method from which the subject-matter of claim 7 differs in that the laminate is fired.

   However, during the sintering step disclosed in D1 a firing step appears to be evident.

   Therefore, claim 7 does not meet the requirements of Article 33.3 PCT.

4. Dependent claims 2-3 and 8 do not contain any features which, in combination with the features of any claim to which they refer, meet the requirements of the PCT in respect of novelty and/or inventive step, the reasons being as follows:

The features of claim 2 are known from D1 (cf. figure 3).
The features of claim 3 are known from D2 (cf. figure 4).
The features of claim 8 are conventional in the art.

5. The structure of the electrode defined by claims 4-6 is neither known from, nor rendered obvious by, the prior art cited in the International Search Report. It is suggested therefore that a new independent claim be drafted to include these features, bearing in mind that the features known in combination in D1 should be placed in the preamble of such a claim in accordance with Rule 6.3(b) PCT.

Re Item VII
Certain defects in the international application

1. Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D1-D2 is not mentioned in the description, nor are these documents identified therein.

2. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

Re Item VIII
Certain observations on the international application

1. Claim 4 lacks clarity, contrary to Article 6 PCT, in that said claim refers to "said first C-shaped ring portions" which are not defined previously.

2. The wording of claims 5 and 6 is confusing; indeed, the claimed electrode structure is not precisely and undoubtedly defined (Article 6 PCT).

10/030592

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
F0063-LAM		
International application No. PCT/JP 99/03701	International filing date (day/month/year) 08/07/1999	(Earliest) Priority Date (day/month/year)
Applicant LAM RESEARCH CORPORATION et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :
      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).
4. With regard to the **title**,
   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established by this Authority to read as follows:
5. With regard to the **abstract**,
   [ ] the text is approved as submitted by the applicant.
   [X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No. 1
   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.
   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP 99/03701

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

The abstract is changed as follows:

An elctrostatic chuck for preventing warpage of a ceramic layer and cooling gas leakage while providing enhanced electrostatic attraction and an improved detachment performance and its manufacturing method is disclosed. The chuck comprises at least one electrode (90,91,92) located in the middle of the ceramic layer(80) in its thickness direction, a cooling gas channel(81) is formed on a surface of the ceramic layer within an outer edge of the electrode and above the electrode, wherein the electrode extends beyond the cooling gas channel. Prererably the electrodes are shaped in the form of two interlocked structures comprising multiple interconnected C-shaped ring portion(91c,92c).

INTERNATIONAL SEARCH REPORT

International Application No
PC[illegible] 99/03701

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/68

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L C23C H02N H01J B23Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 805 487 A (APPLIED MATERIALS INC) 5 November 1997 (1997-11-05)	1,2
A	column 2, line 42 - line 58 column 6, line 43 - line 54 column 8, line 45 -column 12, line 52 column 16, line 29 - line 33 figures 2,10,11 ---	3,4,7,8
A	EP 0 791 956 A (NGK INSULATORS LTD) 27 August 1997 (1997-08-27) page 5, line 45 -page 9, line 6; figures ---	1-4,7
A	EP 0 831 526 A (HITACHI LTD) 25 March 1998 (1998-03-25) column 21, line 23 -column 22, line 55; figure 14 ---	1-4

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 March 2000	22/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Köpf, C

1

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 017, no. 247 (C-1059), 18 May 1993 (1993-05-18) & JP 04 371579 A (ULVAC JAPAN LTD), 24 December 1992 (1992-12-24) abstract -& JP 04 371579 A (ULVAC JAPAN LTD) 24 December 1992 (1992-12-24) paragraphs ‘0013!,‘0014!; figures 3,4 ---	1-4
A	WO 96 13058 A (DIAMOND SEMICONDUCTOR GROUP INC) 2 May 1996 (1996-05-02) page 5, line 25 -page 6, line 31; figure 4 page 10, line 34 -page 12, line 2; figure 8 ---	1,3,4
A	US 5 191 506 A (LOGAN JOSEPH S ET AL) 2 March 1993 (1993-03-02) column 4, line 65 -column 5, line 11; figure 3 -----	4

INTERNATIONAL SEARCH REPORT

Inform[illegible]on patent family members

International Application No
PC[illegible] 99/03701

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 0805487	A	05-11-1997	US	5751537	A	12-05-1998
			JP	10064987	A	06-03-1998
EP 0791956	A	27-08-1997	JP	9134951	A	20-05-1997
			US	5946183	A	31-08-1999
EP 0831526	A	25-03-1998	JP	10150100	A	02-06-1998
			US	5946184	A	31-08-1999
JP 04371579	A	24-12-1992	NONE			
WO 9613058	A	02-05-1996	EP	0871843	A	21-10-1998
			JP	11504760	T	27-04-1999
			US	5822172	A	13-10-1998
US 5191506	A	02-03-1993	DE	69119241	D	05-06-1996
			DE	69119241	T	21-11-1996
			EP	0582566	A	16-02-1994
			JP	2579399	B	05-02-1997
			JP	6506318	T	14-07-1994
			WO	9220093	A	12-11-1992

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 805 487 A3

(12) **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:
04.08.1999 Bulletin 1999/31

(51) Int Cl.6: **H01L 21/68**

(43) Date of publication A2:
05.11.1997 Bulletin 1997/45

(21) Application number: **97302806.1**

(22) Date of filing: **24.04.1997**

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IE IT LI NL SE

(30) Priority: **02.05.1996 US 641938**

(71) Applicant: **APPLIED MATERIALS, INC.**
Santa Clara, California 95054-3299 (US)

(72) Inventors:
- **Kumar, Ananda H.**
  Milpitas, California 95035 (US)
- **Shamouilian, Shamouil**
  San Jose, California 95120 (US)

(74) Representative: **Bayliss, Geoffrey Cyril et al**
BOULT WADE TENNANT,
27 Furnival Street
London EC4A 1PQ (GB)

(54) Multielectrode electrostatic chuck with fuses

(57) A failure resistant electrostatic chuck **20** for holding a substrate **35** during processing of the substrate **35**, is described. The chuck **20** comprises a plurality of electrodes **25** covered by an insulator **30**, the electrodes **25** capable of electrostatically holding a substrate **35** when a voltage is applied thereto. An electrical power bus **40** has a plurality of output terminals **45** that conduct voltage to the electrodes **25**. Fuses **50** electrically connect the electrodes **25** to the output terminals **45** of the power bus **40**, each fuse **50** connecting at least one electrode **25** in series to an output terminal from the power bus **40**. The fuses **50** are capable of electrically disconnecting the electrode **25** from the output terminals **45** when the insulator **30** punctures and exposes the electrode **25** to the process environment causing a current to flow through the fuse **50**. A current detector **175** and electrical counter **180** can be used to provide early detection and counting of the number of failures of the electrodes **25** by detecting the current discharges through the fuses **50**.

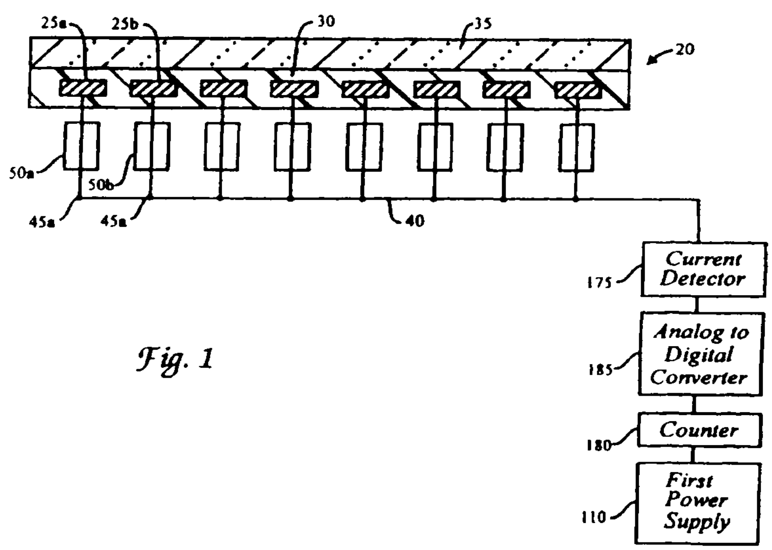


Fig. 1

EP 0 805 487 A3

Printed by Jouve, 75001 PARIS (FR)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 2806

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 015, no. 367 (E-1112), 17 September 1991 & JP 03 145151 A (TOSHIBA CORP), 20 June 1991	1,10,16	H01L21/68
A	* abstract *	2-9, 11-15	
A	US 4 724 510 A (WICKER THOMAS E ET AL) 9 February 1988 * the whole document *	1,3-5, 11-15	
A	EP 0 692 814 A (APPLIED MATERIALS INC) 17 January 1996 * column 10, line 39 - column 13, line 58; figures 1-4 *	11-15	
A	PATENT ABSTRACTS OF JAPAN vol. 18, no. 80 (E-1505), 9 February 1994 & JP 05 291562 A (TOSHIBA CORP), 5 November 1993 * abstract *	1,10,16	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	US 4 281 322 A (NASU TETSUJI ET AL) 28 July 1981 * the whole document *	10,16	H01L
D,A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 564 (E-1013), 14 December 1990 & JP 02 246136 A (FUJITSU LTD), 1 October 1990 * abstract *	10,16	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	10 June 1999	Kirkwood, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 97 30 2806

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

10-06-1999

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4724510 A	09-02-1988	NONE	
EP 0692814 A	17-01-1996	US 5646814 A	08-07-1997
		AT 160238 T	15-11-1997
		DE 69501018 D	18-12-1997
		DE 69501018 T	20-05-1998
		JP 8203991 A	09-08-1996
US 4281322 A	28-07-1981	DE 2940142 A	10-04-1980
		FR 2438335 A	30-04-1980
		GB 2034542 A,B	04-06-1980

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 791 956 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
27.08.1997 Bulletin 1997/35

(51) Int Cl.6: **H01L 21/68**, H01L 21/00

(21) Application number: 96306414.2

(22) Date of filing: 04.09.1996

(84) Designated Contracting States:
DE FR GB

(30) Priority: 06.09.1995 JP 229190/95
20.08.1996 JP 218259/96

(71) Applicant: NGK INSULATORS, LTD.
Nagoya City Aichi Pref. (JP)

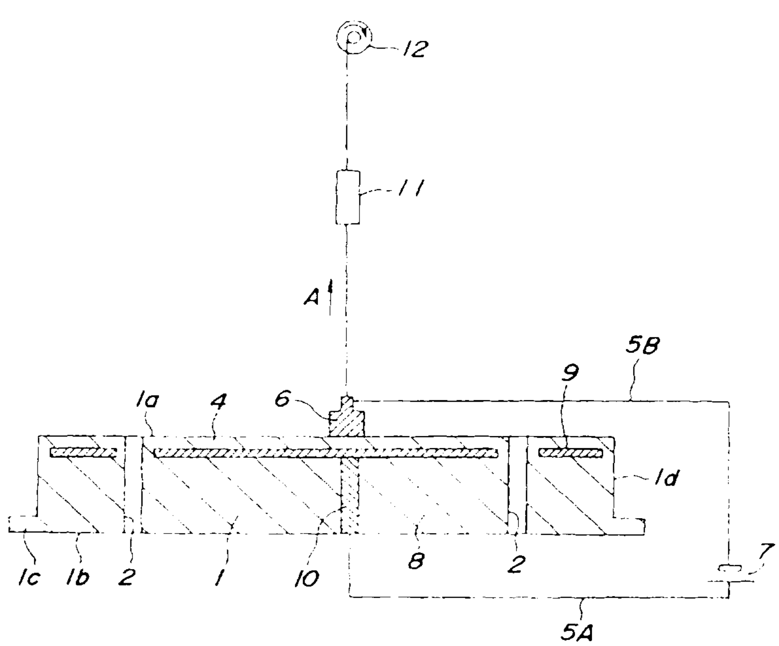
(72) Inventors:
- Yamada, Naohito
  Kasugai City, Aichi Pref. (JP)
- Ohno, Masashi
  Mizuho-Ku, Nagoya City, Aichi Pref. (JP)
- Ushikoshi, Ryusuke
  Tajimi City, Gifu Pref. (JP)

(74) Representative: Paget, Hugh Charles Edward et al
MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP (GB)

(54) **Electrostatic chuck**

(57) An electrostatic chuck for attracting an object to be treated, includes a substrate(1), an insulating dielectric layer (4) and at least one electrode (9) provided between the substrate and the insulating dielectric layer, wherein the above object is to be attracted onto the electrode via the insulating dielectric layer and an average thickness of the insulating dielectric layer (4) is not less than 0.5 mm and not more than 5.0 mm.

FIG_2



EP 0 791 956 A2

Description

Background of the Invention

(1) Field of the Invention

The present invention relates to an electrostatic chuck

(2) Related Art Statement

At present electrostatic chucks are used for attracting and holding semiconductor wafers in conveying film-forming processes such as light exposure. CVD and sputtering fine machining washing etching dicing etc for the semiconductor wafers In JP-B 5-87177 a laminate is produced in a filmy thickness of 30 to 400 μm by successively laminating a first insulating layer a first bonding layer an electrode layer a second bonding layer and a second insulating layer and an electrostatic chuck is produced by bonding this laminate to a metallic substrate The first insulating layer which is arranged between the electrode layer and an object to be treated preferably has a thickness of 5 μm to 75 μm which is tried to be made as small as possible so long as the insulating layer can withstand voltage applied This meets a theory that the smaller the thickness of the insulating dielectric layer of the electrostatic chuck the greater is the attracting force

Turning to this point in more detail the electrostatic attracting force (Coulomb's force) is in inverse proportion to the square of a distance between objects upon which this force acts. As the insulating dielectric layer of the electrostatic chuck becomes thicker the distance between the electrode and the object to be treated proportionally increases Correspondingly the electrostatic attracting force decreases in inverse proportion to the square of the thickness of the insulating dielectric layer. For this reason it is necessary that the insulating layer is made as thin as possible so as to increase the electrostatic attracting force.

In JP-A 2-160444 two or more laminate layers each constituted by an electrode and an insulating layer are formed on a substrate The insulation resistances of the insulating films are made different from each other so that voltage to be applied to each electrode may be selectively controlled. This publication describes that the thickness of each insulating film is appropriately around 300 μm. For in order to increase the electrostatically attracting force the insulating film needs be thinner as mentioned above whereas in order to prevent dielectric breakdown under application of high voltage a certain thickness is necessary. To meet both of these contradictory requirements the thickness of a few tens μm to 300 μm was appropriate As described in JP-A 2-160444 as the temperature rises the volume resistivity of the insulating film decreases Accordingly as the temperature rises the leakage current increases in the insulating film so that the semiconductor film already formed on the the semiconductor wafer is unfavorably broken

Further Japanese Utility Model Application Laid-open No. 2-120831 discloses that grooves are formed on a semiconductor wafer-placing face and helium gas is fed into the grooves That is a substrate to be treated such as a semiconductor wafer need be heated or cooled depending upon the purpose of a process employed. For this reason it is necessary that a heating source or a cooling source is installed under the substrate of the electrostatic chuck and heat is exchanged between the substrate and the semiconductor wafer or the like At that time since the semiconductor wafer merely contacts the attracting surface of the electrostatic chuck so that they are placed in an adiabatic vacuum state inside a vacuum chamber of a semiconductor-producing apparatus That is since no heat conduction occurs through convection heat conduction is very small Thus as mentioned above the grooves are filled with helium gas so that heat may be effectively conducted between the semiconductor wafer and the attracting surface through the helium gas.

When a semiconductor wafer is treated in the state that it is attracted upon an electrostatic chuck such an electrostatic chuck is used over a wide temperature range As mentioned above if the thickness of an insulating film of the electrostatic chuck is about a few μm to 300 μm for example a current leaked from the insulating film largely increases at more than 300°C even though extremely large attracting force may be obtained at room temperature Consequently it was made clear that a semiconductor film already formed on the semiconductor wafer might be broken For this reason a special construction as described in JP-A 2-160444 needed to be employed so that the electrostatic chuck might be used in a high temperature range However such a construction is extremely complex and it does not offer a direct solution against the above problems

It may be considered that a material maintaining a high volume resistivity even at high temperatures is selected or developed However a plastic material having a high volume resistivity generally possess low heat resistance and it is essentially difficult to use such a plastic material in a high temperature range. On the other hand many of ceramic materials having high heat resistance possess their volume resistivity which decrease in a high temperature range In addition to the requirement for the volume resistivity the substrate of the electrostatic chuck must satisfy other requirements such as the mechanical strength but it is generally difficult to select or develop a material satisfying the above

requirements Japanese Utility Model Registration Application Laid-open No 2-120 831 also suffer the above problems

In view of the above the present inventors produced insulating dielectric layers having thicknesses of a few tens μm to 300 μm from various ceramic materials, and examined them with respect to attracting force and leakage current. In general in order to exhibit sufficiently high attracting force the insulating dielectric layer needs to have a volume resistivity of 1 x 10^{13} Ω·cm or less in a use temperature range

It was clarified that an electrostatic chuck having an insulating dielectric layer with a volume resistivity, for example, in a range of 1 x 10^{11} to 1 x 10^{13} Ω·cm at room temperature exhibited high attracting force in a range of room temperature to 200°C, but leakage current largely increased at temperatures of more than 200°C, which might damage a semiconductor wafer. It was also clarified that the electrostatic chuck having the insulating dielectric layer with the volume resistivity of 1 x 10^{14} Ω·cm to 1 x 10^{16} Ω·cm at room temperature had a high attracting force in a temperature range of 100°C to 500°C but its leakage current largely increased when the temperature was more than 500°C so that the semiconductor wafer might be damaged. It was further clarified that in the electrostatic chuck with the insulating dielectric layer having the volume resistivity of 1 x 10^9 Ω·cm to 1 x 10^{10} Ω.cm at room temperature exhibited high attracting force in a temperature range of -20°C to 100°C, but it damaged the semiconductor wafer due to largely increased leakage current at temperatures of more than 100°C.

In this way, it was clarified that although the conventional ceramic electrostatic chucks all exhibited sufficiently high attracting forces in an optimum temperature range, the leakage currents largely increased if the use temperature rose and the volume resistivity of the insulating dielectric ceramic layer decreased to 10^9 Ω·cm or less. Therefore, it was clarified that the conventional electrostatic chucks had a problem in such a use in which a use temperature range is wide, for example, in such a case where various treatments are effected for semiconductor wafers chucked.

Further, in Japanese Utility Model Registration Application Laid-open No. 2-120831, heat needs to be conducted between the semiconductor wafer and the electrostatic chuck uniformly as viewed planarly from the attracting surface thereof. For, even if the temperature of the attracting surface of the electrostatic chuck is equal, a large difference in temperature of the surface of the wafer occurs between a helium gas-filled portion and a helium gas non-filled portion inside the grooves. Consequently, the quality of the resulting semiconductor film varies, which may cause unacceptable products during the production process. Therefore, it is necessary to keep the pressure of the helium gas constant in every portion inside the grooves.

However, in the locations of the actual attracting chuck from which helium gas is to be fed are limited, and their feed openings of the helium gas-feeding locations are away from adjacent ones. Therefore, as the location goes away from a blow-out opening of the helium gas, the pressure of the gas rapidly decreases. In particular, as mentioned above, the thickness of the insulating dielectric layer is merely around a dozen μm to 300 μm, and the insulating dielectric layer merely has a minimum thickness required to maintain a necessary dielectric breakdown strength. This dielectric breakdown strength is a value of a minimum thickness portion of the insulating dielectric layer. For these reasons, the thickness of the grooves must inevitably be set at a few μm to a dozen μm. However, the grooves having a depth of a few μm to a dozen μm gives a large resistance against diffusion of the gas, so that the gas is not sufficiently diffused. Consequently, a large pressure difference occurs inside the grooves and the temperature varies in the semiconductor wafer, so that the quality of the film formed becomes non-uniform. Simultaneously with this, increase in the depth of the grooves causes antonymy that dielectric breakdown may occur between the grooves and the electrode.

Summary of the Invention

It is an object of the present invention to provide an electrostatic chuck for attracting an object to be treated, which can reduce leakage current in a insulating dielectric film to prevent an adverse effect upon the object and simultaneously to maintain the attracting force for the object high, even in a case where the electrostatic chuck is used in a temperature range in which the volume resistivity of the insulating dielectric film is decreased.

It is another object of the present invention to provide an electrostatic chuck for attracting an object to be treated, which can reduce difference in pressure of the gas inside grooves to uniformly conduct heat between every portion of the object and the attracting surface of the electrostatic chuck and simultaneously with this, to reduce the possibility of the dielectric breakdown as small as possible, in a case where a gas introducing hole is provided to be opened at the attracting face of the insulating dielectric layer of the electrostatic chuck and the gas is fed to the grooves or concaves of an attracting face side.

The electrostatic chuck according to the present invention is to attract an object to be treated, and comprises a substrate, an insulating dielectric layer and an electrode provided between the substrate and the insulating dielectric layer, wherein said object is to be attracted onto the electrode via the insulating dielectric layer and the average thickness of the insulating dielectric layer is not less than 0.5 mm and not more than 5.0 mm.

Another electrostatic chuck according to the present invention is to attract an object to be treated, and comprises a substrate, an insulating dielectric layer and an electrode provided between the substrate and the insulating dielectric layer, wherein said object is to be attracted onto the electrode via the insulating dielectric layer, a gas-introducing hole

is provided at least in said insulating dielectric layer while being opened to an attracting surface of the insulating dielectric layer, a gas-diffusing depression is formed in the insulating dielectric layer on a side of said attracting surface and a depth of the gas-diffusing depression is no less than 100 μm and not more than 5.0 mm.

A further electrostatic chuck according to the present invention is to attract an object to be treated, comprises a substrate, an insulating dielectric layer and an electrode provided between the substrate and the insulating dielectric layer, wherein said object is to be attracted onto the electrode via the insulating dielectric layer, a gas-introducing hole is provided at least in said insulating dielectric layer while being opened to an attracting surface of the insulating dielectric layer, a gas-diffusing depression is formed in the insulating dielectric layer on a side of said attracting surface and a distance between a bottom surface of the gas-diffusing depression and the electrode is not less than 500 μm and not more than 5.0 mm.

These and other optional features and advantages of the invention will be appreciated when considered in conjunction with the attached drawings, with the understanding that some modifications, variations and changes of the invention could be easily made by the skilled person in the art to which the invention pertains.

Brief Description of the drawings

Fig. 1 is a sectional view for schematically illustrating a part of an embodiment of the electrostatic chuck according to the present invention;

Fig. 2 is a sectional view for schematically illustrating another embodiment of the electrostatic chuck according to the present invention;

Fig. 3 is a broken perspective view for illustrating an electrode of the electrostatic chuck in Fig. 2 and its vicinity;

Fig. 4 is a perspective view of a preferred net-shaped electrode as an electrode;

Fig. 5(a) is a perspective view for illustrating a preferred punched metal as the electrode, Fig. 5(b) a perspective view for illustrating a round thin plate to be used as the electrode, and Fig. 5(c) a plane view for illustrating a thin plate to be used as the electrode;

Fig. 6 is a further embodiment of the electrostatic chuck according to the present invention;

Fig. 7 is a plane view for schematically illustrating the electrostatic chuck in Fig. 6; and

Fig. 8 is a graph showing the relationship between the surface roughness, Rmax, of the insulating dielectric layer, the voltage applied to the insulating dielectric layer and the attracting force of the electrostatic chuck.

Detailed Description of the Invention

The present inventors have been engaged in investigations of electrostatic chucks made of an insulating ceramic material so that the leakage current may be reduced and the attracting force may be enhanced at various temperatures under vacuum condition. During this investigation, the inventors discovered that the leakage current can be suppressed to a lower level by increasing the thickness of the insulating dielectric layer to not less than 500 μm. Since this is about 10 times as great as the thickness of the insulating dielectric layers of the conventional electrostatic chucks, the amount of the leakage current can be reduced to about 1/10 if the same material is used.

In addition to the above discovery, the present inventors further discovered that even if the thickness of the insulating dielectric layer is increased to not less than 500 μm, the attracting force of the semiconductor wafer is not conspicuously decreased, and attracting force sufficient for attracting the semiconductor wafer can be assured. The present inventors reached the present invention based on the above discovery. That is, it has been considered that since the attracting force decreases in inverse proportion to the square of the thickness of the insulating dielectric layer, an electrostatic chuck with an insulating dielectric layer having such a thickness as increased above could not be used.

It is said that if an electrostatic chuck uses an insulating dielectric layer with a low volume resistivity, charges move, appear at the surface of the dielectric layer, and result in high electrostatic force between the semiconductor wafer and the surface of the dielectric layer under application of voltage. However, the relationship between the thickness of the insulating dielectric layer and the attracting force has not been formulated up to now, and the relationship has not been presumed. Therefore, electrostatic chucks with insulating dielectric layers having thicknesses over the conventional range have not been even investigated in the light of the conventional theory.

However, the present inventors discovered that an electrostatic chuck with an insulating dielectric layer having a thickness of 500 μm to 5.0 mm has sufficiently high attracting force in a temperature range causing reduction in the volume resistivity of the insulating dielectric layer and consequently the inventors accomplished the present invention. In addition, the leakage current is conspicuously reduced, and the possibility of damages upon an object which is attracted to the electrostatic chuck can be diminished.

Specifically, it was discovered that the electrostatic chuck with the insulating dielectric layer having the volume resistivity of 1×10^{11} to 1×10^{13} Ω·cm had high attracting force in a temperature range of room temperature to 200°C, and could stably attract the semiconductor wafer even at more than 200°C, and that the semiconductor wafer did not

peel off from the chuck even when a gas at pressure of 10 to 20 torr was flown between the semiconductor wafer and the attracting face of the chuck in an ordinary manner. It was also discovered that similar results were obtained even at not less than 500°C for the electrostatic chuck with the insulating dielectric layer having the volume resistivity of 1×10^{14} Ω·cm to 1×10^{16} Ω·cm at room temperature. Furthermore, it was discovered that similar results were obtained even at not less than 100°C for the electrostatic chuck with the insulating dielectric layer having the volume resistivity of 1×10^{9} Ω·cm to 1×10^{10} Ω·cm at room temperature.

As mentioned above, it was confirmed that excellent attracting force can be obtained in the electrostatic chuck with the insulating dielectric layer having such a large thickness as the skilled person in the art has not considered, and that the leakage current can be simultaneously largely reduced.

In addition, if the electrostatic chuck is used for a semiconductor-producing apparatus, the chuck is exposed to a halogen based corrosive gas as an etching gas or a cleaning gas. In a process such as sputtering, CVD or etching, the chuck is exposed to plasma. If the insulating dielectric layer made of even a ceramic material is subjected to the halogen based corrosive gas, a reaction product is produced on its surface, and dielectric breakdown may occur starting from any point in a layer of the reaction product through use for a long time under exposure to the plasma. The dielectric breakdown can be assuredly prevented by setting the thickness of the insulating dielectric layer at not less than 500 μm from the standpoint of the corrosion resistance and the plasma resistance.

According to the present invention, the leakage current is more conspicuously reduced by setting the thickness of the insulating dielectric layer at not less than 1.0 mm, whereas the above attracting force is further enhanced by setting the thickness of the insulating dielectric layer at not more than 3.0 mm.

Further, according to the electrostatic chuck of the present invention, the surface roughness, Rmax, of the surface of the insulating dielectric layer is preferably not more than 3 μm. By so doing, the attracting force is particularly increased. If the surface roughness, Rmax, of the insulating dielectric layer is not less than 4 μm, the attracting force is not almost increased even if the voltage applied to the electrodes is increased, whereas if the surface roughness, Rmax, is not more than 3 μm, the attracting force is not only largely increased, but also the attracting force sharply varies to response the increase in the voltage applied to the electrodes.

Further, if the maximum pore diameter of the insulating dielectric layer is set at not more than 5 μm, the surface roughness, Rmax, thereof can be controlled to not more than 3 μm, whereas if the maximum pore diameter is more than 5 μm, the surface roughness, Rmax, of the surface of the insulating dielectric layer could not be controlled to not more than 3 μm even if the surface was finely polished.

The porosity of the insulating dielectric layer is preferably not more than 3 %. For, it was clarified that if the thickness of the insulating dielectric layer falls in the range of the present invention and the surface roughness, Rmax, is set at not more than 3 μm, the attracting force can be most enhanced, when the porosity is not more than 3 %. It was further clarified that if the porosity is more than 3 %, the attracting force was not conspicuously enhanced even if the thickness and Rmax of the insulating dielectric layer are controlled to the above-mentioned respective ranges, the attracting force could not be conspicuously enhanced.

The electrostatic chuck according to the present invention with the insulating dielectric layer having the volume resistivity of not more than 1×10^{13} Ω·cm can afford high attracting force, and can be favorably used in practice. Particularly, when the volume resistivity of the insulating dielectric layer is even in a range of not more than 1×10^{9} Ω·cm to not less than 1×10^{7} Ω·cm, sufficiently high attracting force can be obtained, and leakage current can be conspicuously reduced.

The volume resistivity of the insulating dielectric layer is more preferably set at not less than 1×10^{8} Ω·cm from the standpoint of the reduction in the leakage current. However, if the leakage current up to about 10 mA is acceptable with respect to an 8-inch wafer, excellent effects can be obtained according to the present invention even if the volume resistivity of the insulating dielectric layer is in a range of 1×10^{7} Ω·cm to 1×10^{8} Ω·cm.

When the insulating dielectric layer of the electrostatic chuck according to the present invention is provided with grooves or depressions for dispersing a gas over the attracting face of the insulating dielectric layer as mentioned above, the gas can be uniformly dispersed or diffused in the gas-diffusing depression if the depth of depression is set at not less than 100 μm so that the temperature of a target object to be treated, such as a semiconductor wafer may be made uniform. As mentioned above, if the thickness of the insulating dielectric layer is more than 5.0 mm, the attracting force decreased. Therefore, the depth of the gas-diffusing depression is preferably not more than 5.0 mm.

The present invention can be embodied in an electrostatic chuck as shown in Fig. 1. An electrode 33 is formed on a substrate 31, and an insulating dielectric layer 32 is made upon the electrode 33. A gas-diffusing depression 34 is provided to be opened at a surface side of the insulating dielectric layer 32, and a gas-introducing hole 35 is communicated with the gas-diffusing depression 34. The gas-introducing hole 35 is opened at a surface side of the substrate 31, and connected to a gas feeder not shown. A gas is flown into the gas-diffusing depression 34 through the gas-introducing hole 35 as shown by an arrow E.

The depth t of the gas-diffusing depression 34 as measured from the attracting face is greater than that g of the electrode 33 from the attracting face, so that the electrode is buried in the substrate, while avoiding the location of the

gas-diffusing depression 34. That is, the electrode 33 is buried in the substrate such that the electrode 33 is removed in an area in which the gas-diffusing depression 34 exists and the peripheral portion of the electrode 33 is not exposed to the gas-diffusing depression. In this case, the distance "1" between the peripheral portion of the electrode 33 and the gas-diffusing depression 34 must be about 1 mm so as to prevent dielectric breakdown. Owing to this, since the the electrode 33 is completely missing in the gas-diffusing depression 34 and its vicinity, the attracting force cannot be obtained there at all.

Therefore, the electrode is preferably laid further under the gas-diffusing depression so that the attracting force may be generated over the entire attracting face of the chuck including the gas-diffusing depression. In this case, dielectric breakdown can be assuredly prevented by setting the distance between the bottom of the gas-diffusing depression and the electrode at not less than 500 μm.

In a particularly preferable embodiment, the thickness of the insulating dielectric layer is set at not less than 1 mm; the depth of the gas-diffusing depression is not less than 100 μm, and preferably not less than 500 μm; and the electrode is laid further under the gas-diffusing depression, while the distance between the electrode and the bottom face of the gas-diffusing depression is set at as much as not less than 500 μm. If the thickness of the insulating dielectric layer is increased like this, the electrode needs not be partially omitted even if the depth of the gas-diffusing depression is made large enough to excellently diffuse the gas. Consequently, the electrostatic attracting force can be generated over a wider area. In this embodiment, the thickness of the insulating dielectric layer is not more than 5.0 mm, more preferably not more than 3.0 mm, whereas the depth of the gas-diffusing depression is not more than 3.0 mm, and particularly preferably not more than 2.0 mm. In addition, the distance between the electrode and the bottom face of the gas-diffusing depression is preferably not more than 3.0 mm, particularly preferably not more than 2.0 mm.

Since the thickness of the insulating dielectric layer is not more than 300 μm in the conventional electrostatic chuck, it is necessary to employ a green ceramic sheet-laminating process, a gas phase growing process or a plasma spraying process, which unfavorably causes a high production cost. However, according to the present invention, an insulating dielectric body having a thickness of a few mm is produced by sintering, which is ground to make an attracting face of the resulting insulating dielectric layer flat, while a gas-diffusing depression is formed by machining. By so doing, the production cost can be conspicuously reduced.

The electrostatic chuck according to the present invention can be used as a plasma-generating electrode unit by connecting the electrode of the chuck to a high frequency electric power source and simultaneously applying a DC voltage and a high frequency voltage to the electrode. In this case, if the electrode is made of tungsten and the frequency of the high frequency voltage is 13.56 MHz, the thickness of the electrode is preferably not less than 430 μm. However, since it is difficult to form the electrode of such a thickness by screen printing, the electrode is preferably constituted by a metallic bulky body. If the thickness of the insulating dielectric layer is in a range of 0.5 mm to 5.0 mm, self heat generation due to the energy loss of the dielectric body is not so great if the dielectric loss tangent is not more than 0.1 at the above frequency. Thus, the electrostatic chuck can be used as the high frequency electrode unit without a problem.

When the electrostatic chuck according to the present invention was installed in a semiconductor-producing apparatus using a halogen based corrosive gas, the chuck was corroded with the halogen based corrosive gas such as ClF_3 in some case. If such an electrostatic chuck may be exposed to the halogen based corrosive gas, an electrostatic chuck may be preferably used in such a case, which includes a substrate of a dense ceramic material, an insulating dielectric layer of a dense ceramic material, and an electrode of a planar metallic bulky body integrally sintered. In this electrostatic chuck, since the substrate surrounding the electrode is an monolithic sintered body having no joining face, the electrode can be prevented from the corrosion.

As the ceramic material constituting the substrate and the insulating dielectric layer, nitride-based ceramic materials such as silicon nitride, aluminum nitride, boron nitride, and sialon, silicon carbide and alumina-silicon nitride composite material are preferred. From the standpoint of thermal shock resistance, silicon nitride is particularly preferred. From the standpoint of the corrosion resistance against the halogen based corrosive gas, aluminum nitride is particularly preferred.

Aluminum nitride is a material which is particularly hard to be sintered. For this reason, it is difficult to obtain a sintered body having a relatively high density by a conventional pressureless sintering process. Therefore, it has been a common practice to promote the sintering of aluminum nitride by incorporating a large amount of sintering aids into aluminum nitride powder. However, particularly if the resulting chuck is installed in the semiconductor-producing apparatus, such sintering aids act as impurities, which may cause contamination of the semiconductor.

Meanwhile, a sintered body obtained by hot press sintering a mixture of aluminum nitride powder added with 5 % yttria as a sintering aid had a relative density of more than 99 %, and exhibited excellent corrosion resistance against the halogen based corrosive gas. Furthermore, when aluminum nitride powder containing not more than 1 % of impurities was used, a dense sintered body having a relative density of more than 99 % could be obtained by hot press sintering the powder. Therefore, an electrostatic chuck made of aluminum nitride having purity of not less than 95 % and particularly not less than 99 % with excellent corrosion resistance could be produced.

The electrostatic chuck according to the present invention may be produced by the following process. First, a planar electrode made of a metallic bulky body is buried in a ceramic green body. This step is carried out as follows:

Method 1.

A preliminarily green body is prepared, and the above electrode is placed on this preliminarily green body. Then, a ceramic powder is charged over this electrode on the preliminarily green body, and the resultant is uniaxially press molded.

Method 2.

Two planar green bodies are prepared by cold isostatic press, and an electrode is held between two planar green bodies. Then, the assembly of the two green bodies and the electrode is hot pressed in this state.

In the method 2, the density of the preliminarily green body is increased and the variation in density of the green body is smaller owing to the cold isostatic press, as compared with the method 1. Therefore, as compared with the method 1, a shrinkage amount of the green body during the hot press is smaller and variation in density is smaller after the firing. As a result, the average dielectric strength of the sintered body is relatively larger.

The above function and effect is particularly important for the electrostatic chuck. For, due to the above-mentioned reasons, the average dielectric strength of the dielectric layer of the electrostatic chuck can be further enhanced, and its reliability can be greatly high.

In this sense, the relative density of the green body obtained by the cold isostatic press is most preferably not less than 60 %.

Further, in order to screen print an electrode on a surface of a green body obtained by the cold isostatic press process, the green body needs be dewaxed for a long time under a non-oxidizing atmosphere. In this respect, since such an extended time dewaxing step does not exist in a case where the electrode is held between the green bodies obtained by the cold isostatic press, this case is advantageous from the standpoint of the mass production.

Further, assume that the filmy electrode is formed by the screen printing. It is considered that since the filmy electrode is deformed during the hot pressing, another problem consequently occurs that the thickness of the dielectric layer on the electrode film becomes non-uniform. In this respect, since the deformation of the electrode can be prevented by the rigidity of the electrode itself during the hot pressing when the electrode made of a planar metallic bulky body is buried, the non-uniform thickness of the dielectric layer can be prevented. The thickness of the dielectric layer is important for the electrostatic chuck, because this thickness rules the chucking performance. The wording "planar metallic bulky body" used here means, for example, a metallic bulky body formed as a monolithic planar shape as shown in Figs. 3, 4 and 5 without forming a wire body or a planar body in a spiral or meandered or zigzag shape.

Since the electrode is subjected to hot press in its thickness direction, it is preferably a planar electrode from the standpoint of preventing the warping during the hot press. The electrode is preferably made of a high melting point metal in an application where the temperature is raised to a high temperature of 600°C or more at the maximum.

As such a high melting point metal, tantalum, tungsten, molybdenum, platinum, rhenium, hafnium and their alloys may be recited. From the standpoint of preventing contamination of the semiconductors, tantalum, tungsten, molybdenum, platinum and their alloys are preferred. As an object to be treated by using the electrostatic chuck, aluminum wafers may be recited by way of example in addition to the semiconductor wafers.

The configuration of the electrode includes a planar electrode having a number of small holes, and a net-shaped electrode besides the thin planar electrode. When the planar electrode having a number of the small holes or the net-shaped electrode is used as the electrode, the ceramic powder flows around through the numerous small holes or meshes, the joining force between the substrate and the insulating dielectric layer on the opposite sides of the electrode becomes greater to enhance the strength of the substrate. Further, when the electrode takes a thin planar shape, a large stress occurs particularly at the peripheral portion of the electrode, so that the substrate might be broken due to this stress. However, when the electrode is the planar body having numerous small holes or the net body, that stress is effectively dispersed by numerous small holes and meshes.

As the planar body having numerous small holes, a punched metal may be recited by way of example. However, when the electrode is to be made of a high melting point metal punched, such a high melting point metal itself has high hardness. Thus, it is difficult to punch numerous small holes in such a high melting point metal, and such punching raises a working cost.

In this respect, when the electrode is made of a metal net, wires made of the high melting point metal are easily available, and the metal net can be easily produced by knitting the wires. Therefore, the electrode can be easily produced by using such wires.

The mesh shape, the wire diameter, etc. of the metal net are not particularly limited. However, the metal nets having a wire diameter range of 0.03 mm to 0.5 mm and a mesh range of 150 meshes to 6 mesh could be used without

no particular problem Further the sectional shape of the wires constituting the metal net as viewed in the width direction may be circular elliptical rectangular or variously rolled shapes

Preferred embodiments of the present invention will be explained below with reference to the drawings

Fig 2 is a sectional view schematically illustrating an electrostatic chuck Fig 3 is a perspective view showing the electrostatic chuck in Fig 2 partially cut off Fig 4 is a perspective view showing an electrode 3 made of a metal net

A ring-shaped flange lc is provided at a peripheral face ld of a substrate 1 having an almost discoidal shape and an electrode 9 made of a metal net 3 is buried inside the substrate 1 An insulating dielectric layer 4 is formed in a given thickness on a surface of the substrate 1 on a side la upon which an object to be treated such as a semiconductor wafer is to be placed The thickness of the insulating dielectric layer 4 is selectively determined according to the present invention A terminal 10 is buried in a supporting portion 8 of the substrate 1 one end of the terminal 10 being connected to the electrode 9 while the other end face of the terminal 10 being exposed outside at the rear surface lb of the substrate Formed in the substrate 1 at given locations are holes 2 for lifting pins to vertically move the semiconductor wafer

A DC electric power source 7 is connected to the terminal 10 via an electric wire 5A In order to measure an attracting force of the electrostatic chuck, a stainless weight 6 is arranged on the attracting face la, and an electric wire (earthed wire) 5B is connected to the stainless weight 6 The stainless weight 6 is connected to a load cell 11 for the measurement of a load, and the stainless weight 6 connected to the load cell 11 is pulled up in a direction of an arrow A by means of a stepping motor 12. The attracting force can be determined by a formula: (load at which the weight 6 is released from the attracting face of the dielectric layer - a mass of the weight)/(the sectional area of the weight on the attracting surface)

The electrode 9 is constituted by a metal net 3 as shown in Figs 3 and 4. The metal net is constituted by a circular frame wire 3a and wires 3b which are vertically and laterally arranged inside the frame wire 3a to form meshes between them

Fig 5(a) is a perspective view of a punched metal 14 to be used as an electrode 9 The punched metal 14 has a circular shape, and a number of round holes 14b are formed in a circular flat plate 14a as in a checkered pattern

Fig 5(b) is a perspective view for showing a round thin plate 15 to be used as the electrode 9 Fig 5(c) is a plane view of a thin plate 16 to be used as the electrode 9 In the thin plate 16, linear slender cuts 16b and 16c are formed in parallel in totally six lines. Among these linear slender cuts, three linear slender cuts 16b are opened to a lower side in Fig 5c, and the remaining three linear slender cuts 16c are opened to the upper side These cuts 16b and 16c are alternatively arranged. Since such a configuration is used for the electrode, a thin and long conductive passage is formed in the thin plate. Terminals are connected to opposite ends 16a of the conductive passage

Fig 6 is a sectional view for schematically illustrating another preferred embodiment of the electrostatic chuck according to the present invention, and Fig. 7 is a plane view for illustrating the electrostatic chuck in Fig. 6 A ring-shaped flange 18c is provided at a peripheral face 18d of a substrate 18 having an almost discoidal shape and an electrode 9 is buried inside the substrate 9 An insulating dielectric layer 40 is formed on a surface of the substrate 18 on a side 18a upon which an object to be treated, such as a semiconductor wafer, is to be placed A terminal 10 is buried in a supporting portion 8 of the substrate 18, one end of the terminal 10 being connected to the electrode 9 while the other end face of the terminal 10 being exposed outside at the rear surface 18b of the substrate 18

A DC electric power source 7 is connected to the terminal 10 via an electric wire 5A. The object 41 is placed on the attracting face 18a, and is connected to a negative pole of the DC electric power source 7 and an earth 23 via an electric wire 5B Gas-introducing holes 42 are formed in the substrate 18 at given locations and continued to a gas-diffusing depression 24A In this embodiment, the gas-diffusing depression 24A surrounds a circular discoidal portion 27, and the four gas-introducing holes 42 are provided at symmetrical locations at an equal interval such that the gas-introducing holes are opened to the gas-diffusing depression 24A. Numerous small projections 26 are regularly provided on the discoidal portion 27

Linear gas-diffusing depressions 24B are radially outwardly extended from the gas-diffusing depression 24A. Among the gas-diffusing depressions 24B are formed totally eight trapezoidal-section portions 29 A number of circular projections 26 are also regularly provided on each of the trapezoidal-section portions 29 An annular projection 25 is provided at an outer peripheral side of the trapezoidal-section portions 29 so as to surround the entire attracting surface. The end of each of the gas-diffusing depressions 24B is partitioned by the projection 25

Gas feed pipes 22 are connected to openings of the gas-introducing holes 42 on the rear face side 18b, and this feed pipes 22 are in turn connected to a feeder not shown A resistive heating element 19 is buried in the supporting portion 8 of the substrate 18, and terminals 20 are connected to the opposite ends of the resistive heating element 19. To each of the terminals 20 is connected an electric power feed cable 21, and the cable 21 is in turn connected to an electric power source

According to the present invention, the thickness g of the insulating dielectric layer 40 is selected to be in a range of 500 μm to 5 0 mm The depth t of the gas-diffusing depressions 24A and 24B and the distance s between the bottom face of the gas-diffusing depression and the electrode are selectively determined according to the present invention

On operation of the electrostatic chuck, a gas is fed through the feed pipes 22 in an arrow B direction, passed through the gas-introducing holes 42, and blown out from their outlets on the attracting surface side in arrow C directions. The gas flows in the gas-diffusing depression 24A in an arrow D direction in a circular shape as viewed in plane, and also flows toward the projection 25 through the gas-diffusing depressions 24B in the arrow C directions. The gas is dispersed over the circular discoidal and trapezoidal-section portions 27, 29 excluding the round projections 26 so that the gas may be uniformly dispersed all over the rear face of the object to be treated.

The residual attracting force upon the object to be treated can be controlled by the design of the projections 26 so that the residual attracting force may not be excessive.

(Experiments)

In the following, more concrete experimental results will be explained.

(Experiment 1)

An electrostatic chuck as shown in Figs. 6 and 7 was produced. An electrode was buried in a green body composed of aluminum nitride powder having a purity of 99.9 %, and a sintered body was obtained by hot press sintering the green body at the hot press temperature of 1910°C, so that the volume resistivity of an insulating dielectric layer was controlled to 1×10^{11} Ω·cm at room temperature.

As an electrode, a metal net made of molybdenum was used. This metal net was obtained by knitting molybdenum wires having a diameter of 0.12 mm at a density of 50 wires per one inch. The surface of the insulating dielectric layer was machined to adjust the thickness thereof. A hole was formed in the sintered body from a rear face side by using a machining center, and a terminal was joined to the electrode. The relative density of the aluminum nitride sintered body constituting the substrate and the insulating dielectric layer was 99 %.

The average thickness of the insulating dielectric layer was varied as shown in Table 1. Each electrostatic chuck was placed in a vacuum chamber, and electric power was applied to a resistive heating element 19 in a controlled condition so that the temperature of the electrostatic chuck might be 200°C. The volume resistivity of the insulating dielectric layer at 200°C was 2×10^{8} Ω·cm. The attracting force was measured by the method explained with reference to Fig. 2. The voltage was 500 V or 1000 V. Results in the voltage of 500 V are given in Table 1, and those in the voltage 1000 V are shown in Table 2. The measurement values are given with respect to unit of 5 g/cm^2.

Table 1

Thickness of insulating dielectric layer (mm)	0.3	0.5	1.0	1.5	2.0
Attracting force (g/cm^2)	280	210	135	95	60
Thickness of insulating dielectric layer (mm)	3.0	4.0	5.0	6.0	-
Attracting force (g/cm^2)	45	35	30	5	-

Table 2

Thickness of insulating dielectric layer (mm)	0.3	0.5	1.0	1.5	2.0
Attracting force (g/cm^2)	395	360	180	155	105
Thickness of insulating dielectric layer (mm)	3.0	4.0	5.0	6.0	-
Attracting force (g/cm^2)	60	45	40	10	-

As is clear from the results, reduction in the attracting force is relatively small in the case of the insulating dielectric layer being in a thickness range of 0.5 to 5.0 mm, and preferably in a thickness range of 1.0 to 3.0 mm. In particular, a semiconductor could be sufficiently stably attracted in the case that the pressure of the gas was about 20 torr.

(Experiment 2)

An electrostatic chuck was produced in the same manner as in Experiment 1, and the attracting force was tested in the same way as in Experiment 1. In Experiment 2, the hot press temperature was set at 1800°C, and the volume resistivity of the insulating dielectric layer was controlled to 1×10^{15} Ω·cm at room temperature.

The electrostatic chuck was placed in a vacuum chamber, and was heated up to 400°C by feeding electric power

to a resistive heating element. The volume resistivity of the insulating dielectric layer at 400°C was 5 x 10^8 Ω·cm. The voltage applied to the electrostatic chuck was 500 V. Results are shown in Fig. 3 with respect to the insulating dielectric layers having different average thicknesses. An area of an attracting portion of the stainless weight 6 used to test the attracting force was 1 cm^2, and the leakage current flown to the weight was simultaneously measured. Since the area of an 8-inch semiconductor wafer is about 300 cm^2, a leakage current which would flow the 8-inch wafer was presumed by multiplying a measurement value by 300. The thus obtained leakage currents are shown in Table 3.

Table 3

Thickness of insulating dielectric layer (mm)	0.3	0.5	1.0	1.5	2.0
Attracting force (g/cm^2)	260	205	130	110	75
Leaked current in 8 inch size (mA)	20	8	3	1.5	1
Thickness of insulating dielectric layer (mm)	3.0	4.0	5.0	6.0	-
Attracting force (g/cm^2)	60	25	20	0	-
Leaked current in 8 inch size (mA)	0.5	0.3	0.2	0.2	-

The smaller the thickness of the insulating dielectric layer, the larger is the intensity of the electric field (voltage/thickness). As is seen from Table 3, it seems that the larger the intensity of the electric field, the more likely does the current flow, but the amount of the current was not in inverse proportion to the thickness of the insulating dielectric layer.

Therefore, even when the volume resistivity of the insulating dielectric layer was reduced down to 10^8 Ω·cm, the leakage current in the wafer having a large area like the 8-inch wafer could be largely reduced, and the attracting force was sufficient for holding such a wide-area wafer.

(Experiment 3)

An electrostatic chuck having such a configuration as shown in Figs. 6 and 7 was produced in the same manner as in Experiment 1. The hot press temperature was set at 1910°C, and the volume resistivity of the insulating dielectric layer was controlled to 1 x 10^{11} Ω·cm at room temperature. The thickness of the insulating dielectric layer was adjusted to 1.0 mm.

The porosity, the maximum pore diameter, and the surface roughness, Rmax, of the insulating dielectric layer were controlled as shown in Tables 4 and 5.

The porosity of 0.1 % and the maximum pore diameter of 0.5 μm were attained by setting the hot press pressure at 200 kg/cm^2. The densification was suppressed by setting the hot press pressure at not more than 50 kg/cm^2, so that a sintered body having a porosity of 3 % or 5 % and a maximum pore diameter of 1 μm or 2 μm was obtained. Further, metallic aluminum was incorporated as a pore-forming agent into a powdery raw material, so that a sintered body having the maximum pore diameter of 5 μm or 10 μm was obtained, and influences of machining conditions upon the surface roughness, Rmax, were examined from various aspects.

Each electrostatic chuck was placed in a vacuum chamber, and the electrostatic chuck was controlled to 100°C by feeding electric power to a resistive heating element 19. The volume resistivity of the insulating dielectric layer at 100°C was 8 x 10^9 Ω·cm. The attracting force was measured by the method explained with reference to Fig. 2. The voltage was set at 250 V, 500 V or 750 V. Measurement results of the attracting force are shown in Tables 4 and 5 and Fig. 8.

Table 4

Surface roughness, Rmax, of insulating dielectric layer (μm)	Porosity of insulating dielectric layer (%)	maximum Pore diameter of insulating dielectric layer (μm)	Voltage applied to insulating dielectric layer (V)	Attracting force of electrostatic chuck (g/cm^2)
9	0.1	0.5	250	20
9	0.1	0.5	500	35
9	0.1	0.5	750	40
4	0.1	0.5	250	40
4	0.1	0.5	500	55

Table 4 (continued)

Surface roughness. Rmax. of insulating dielectric layer (µm)	Porosity of insulating dielectric layer (%)	maximum Pore diameter of insulating dielectric layer (µm)	Voltage applied to insulating dielectric layer (V)	Attracting force of electrostatic chuck (g/cm^2)
4	0.1	0.5	750	60
3	0.1	0.5	250	100
3	0.1	0.5	500	170
3	0.1	0.5	750	230
1	0.1	0.5	250	210
1	0.1	0.5	500	470
1	0.1	0.5	750	720

Table 5

Surface roughness. Rmax. of insulating dielectric layer (µm)	Porosity of insulating dielectric layer (%)	Maximum pore diameter of insulating dielectric layer (µm)	Voltage applied to insulating dielectric layer (V)	Attracting force of electrostatic chuck (g/cm^2)
3	3	1	250	95
3	3	1	500	160
3	3	1	750	210
3	5	2	250	40
3	5	2	500	60
3	5	2	750	95

As is clear from the above results. if the surface roughness. Rmax. of the insulating dielectric layer is not less than 4 µm. the attracting force is not almost increased even if the voltage applied to the insulating dielectric layer is raised. whereas if the surface roughness. Rmax. is not more than 3 µm. the attracting force is not only increased but also the attracting force sharply varies to respond to the increase in the voltage applied to the insulating dielectric layer. Further. it was also clarified that if the surface roughness. Rmax. is set at not more than 3 µm and if the porosity is set at not more than 3 %. the attracting force is most enhanced. Examination of various maching conditions revealed that if the maximum pore diameter of the insulating dielectric layer is not more than 5 µm. the surface roughness. Rmax. can be controlled to 3 µm.

(Experiment 4)

An electrostatic chuck as shown in Figs. 6 and 7 was produced. Aluminum nitride powder containing yttria as a sintering aid and having a purity of 95 % was used. An electrode was buried in a green body composed of this powder. and a sintered body was produced by hot press sintering the green body. As the electrode. a metal net made of molybdenum was used. A metal net obtained by knitting molybdenum wires having diameter of 0.3 mm at a density of 20 wires per inch was used. A molybdenum wire was buried as a resistive heating element. The surface of an insulating dielectric layer was machined to set its thickness at 3.0 mm. A hole was formed from a rear face side by using a machining center. and a terminal was joined to the electrode.

Round projections 26. a circular portion and trapezoidal-section portions were formed by sand blasting such that the height of the projections 26 from the circular portion or the trapezoidal-section portions were 20 µm. Each of gas-diffusing depressions was 3.0 mm in width and 1.0 mm in depth. The distance between the bottom face of the gas-diffusing depression and the electrode was 2.0 mm.

The relative density of the aluminum nitride sintered body constituting the substrate and the insulating dielectric layer was 99.9 %. In this case. if the dielectric breakdown resistance is at least 10 kV/mm and the distance between the bottom face of the gas-diffusing depression and the electrode is 500 µm. the dielectric breakage resistance is not

less than 5 kV This gives 5 times safety degree as considered from the driving voltage of the electrostatic chuck of 500 V to 1000 V Further if the average thickness of the insulating dielectric layer is set at 3 0 mm. the distance between the bottom face of the gas-diffusing depression and the electrode can be 2 0 mm even if the depth of the gas-diffusing depression is 1 0 mm Thus the electrode needs not be partially removed there

As mentioned above according to the present invention even if the electrostatic chuck for attracting an object to be treated is used in the temperature range in which the volume resistivity of the insulating dielectric layer would decrease the leakage current in the insulating dielectric film can be reduced and the object-attracting force can be simultaneously sufficiently highly maintained

Further when the gas-introducing hole is formed in the electrostatic chuck and opened at the attracting face of the insulating dielectric layer and the gas is fed to the depression at the attracting face the difference in pressure inside the depression can be reduced so that heat conduction may be made uniform between the attracting surface of the chuck and every portion of the object to be treated and that the dielectric breakdown between the depression and the electrode can be prevented

Claims

1. An electrostatic chuck for attracting an object to be treated. comprising a substrate. an insulating dielectric layer and at least one electrode provided between the substrate and the insulating dielectric layer. wherein said object is to be attracted onto said at least one electrode via the insulating dielectric layer and an average thickness of the insulating dielectric layer is not less than 0 5 mm and not more than 5 0 mm.

2. The electrostatic chuck set forth in Claim 1. wherein said insulating dielectric layer is comprised of a dense ceramic material.

3. The electrostatic chuck set forth in Claim 1. wherein each of said substrate and the insulating dielectric layer is comprised of a dense ceramic material. said at least one electrode is composed of a planar metallic bulky body. and the substrate. the insulating dielectric layer and at least one electrode are integrally sintered.

4. The electrostatic chuck set forth in any one of Claims 1 to 3. wherein a resistive heating element is buried in the substrate.

5. The electrostatic chuck set forth in any one of Claims 1 to 4. which further comprises a high frequency electric power source for feeding a high frequency electric power upon said at least one electrode so as to generate plasma upon said object.

6. An electrostatic chuck for attracting an object to be treated. comprising a substrate. an insulating dielectric layer and at least one electrode provided between the substrate and the insulating dielectric layer. wherein said object is to be attracted onto at least one electrode via the insulating dielectric layer. a gas-introducing hole is provided at least in said insulating dielectric layer while being opened to an attracting surface of the insulating dielectric layer. at least one gas-diffusing depression is formed in the insulating dielectric layer on a side of said attracting surface. and a depth of the gas-diffusing depression is no less than 100 μm and not more than 5.0 mm.

7. The electrostatic chuck set forth in Claim 6. wherein said at least one electrode is present between the gas-diffusing depression and the substrate as viewed from a side of the attracting surface of the insulating dielectric layer.

8. An electrostatic chuck for attracting an object to be treated. comprising a substrate. an insulating dielectric layer and at least one electrode provided between the substrate and the insulating dielectric layer. wherein said object is to be attracted onto at least one electrode via the insulating dielectric layer. a gas-introducing hole is provided at least in said insulating dielectric layer while being opened to an attracting surface of the insulating dielectric layer. at least one gas-diffusing depression is formed in the insulating dielectric layer on a side of said attracting surface. and a distance between a bottom surface of the gas-diffusing depression and at least one electrode is not less than 500 μm and not more than 5 0 mm

9. Semiconductor wafer processing apparatus having an electrostatic chuck according to any one of claims 1 to 8.

FIG. 1

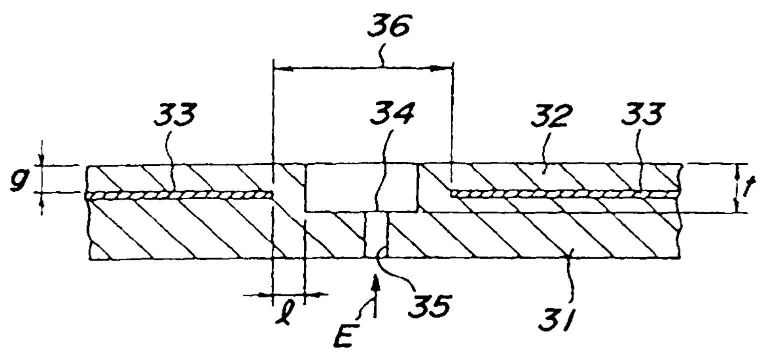


FIG_2

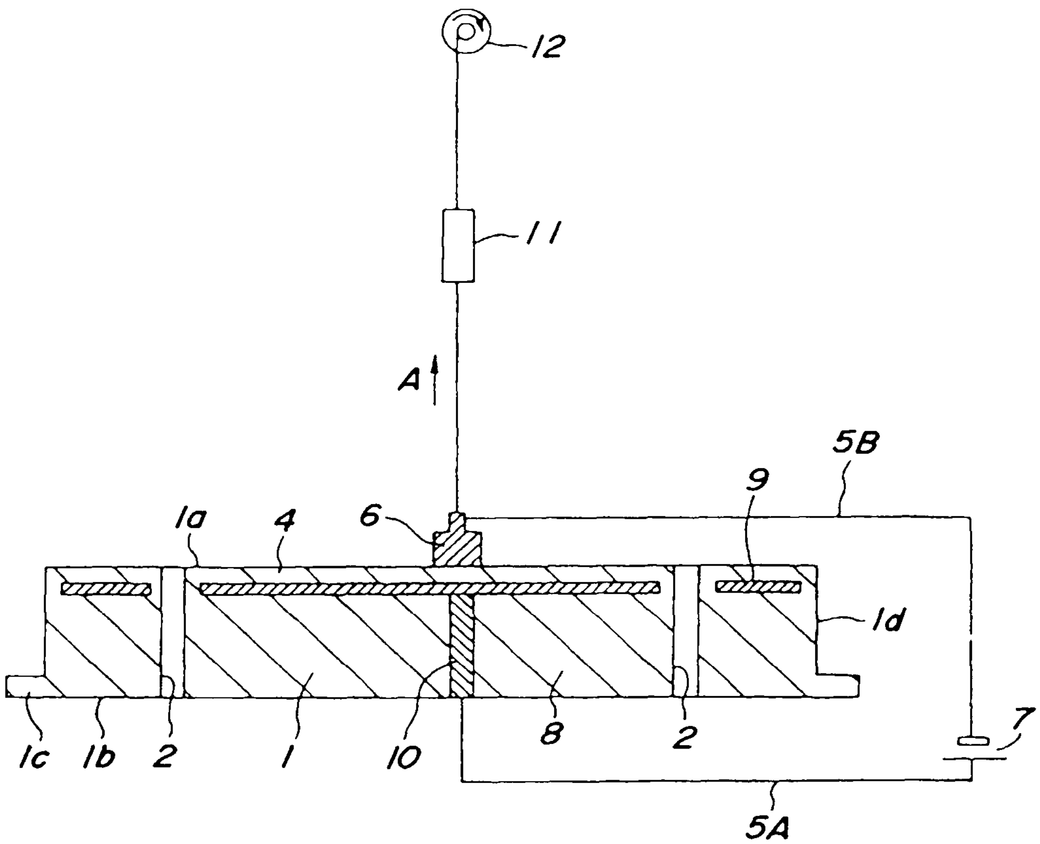


FIG_3

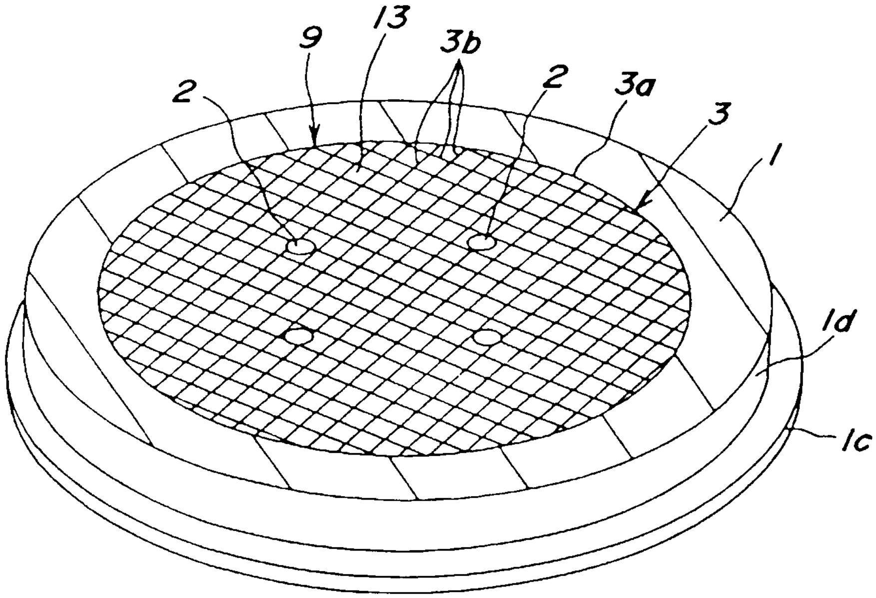


FIG_4

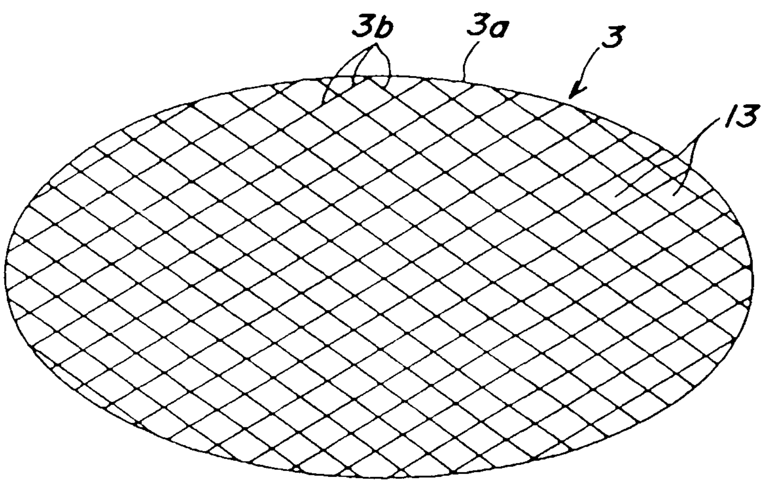


FIG_5a

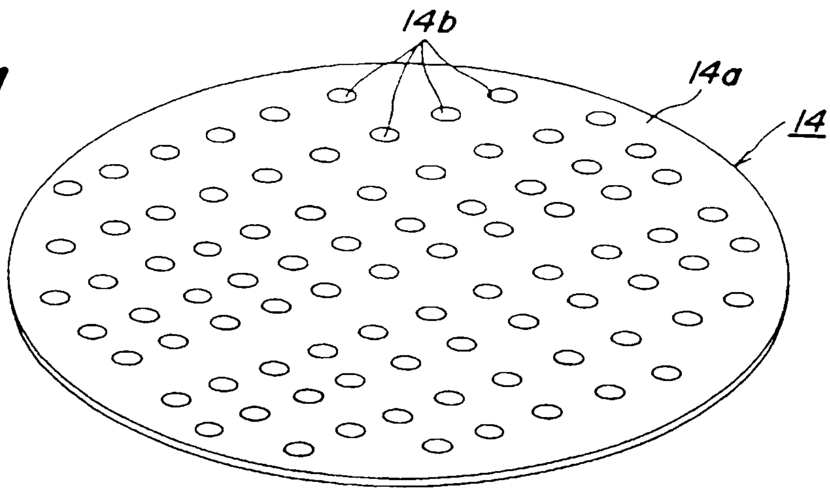


FIG_5b

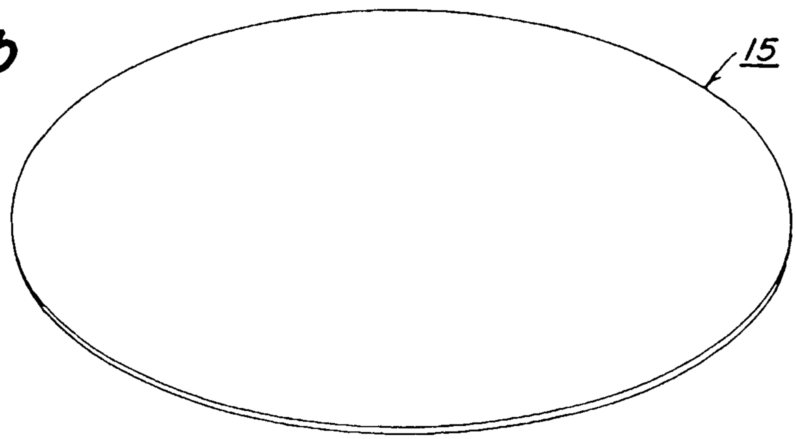


FIG_5c

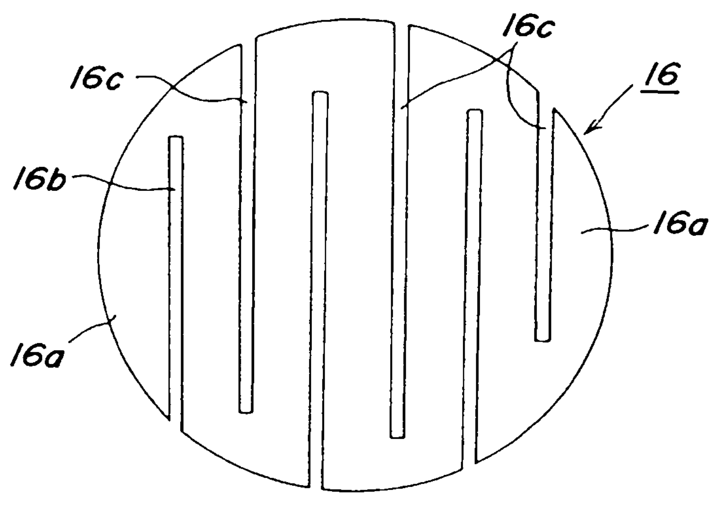
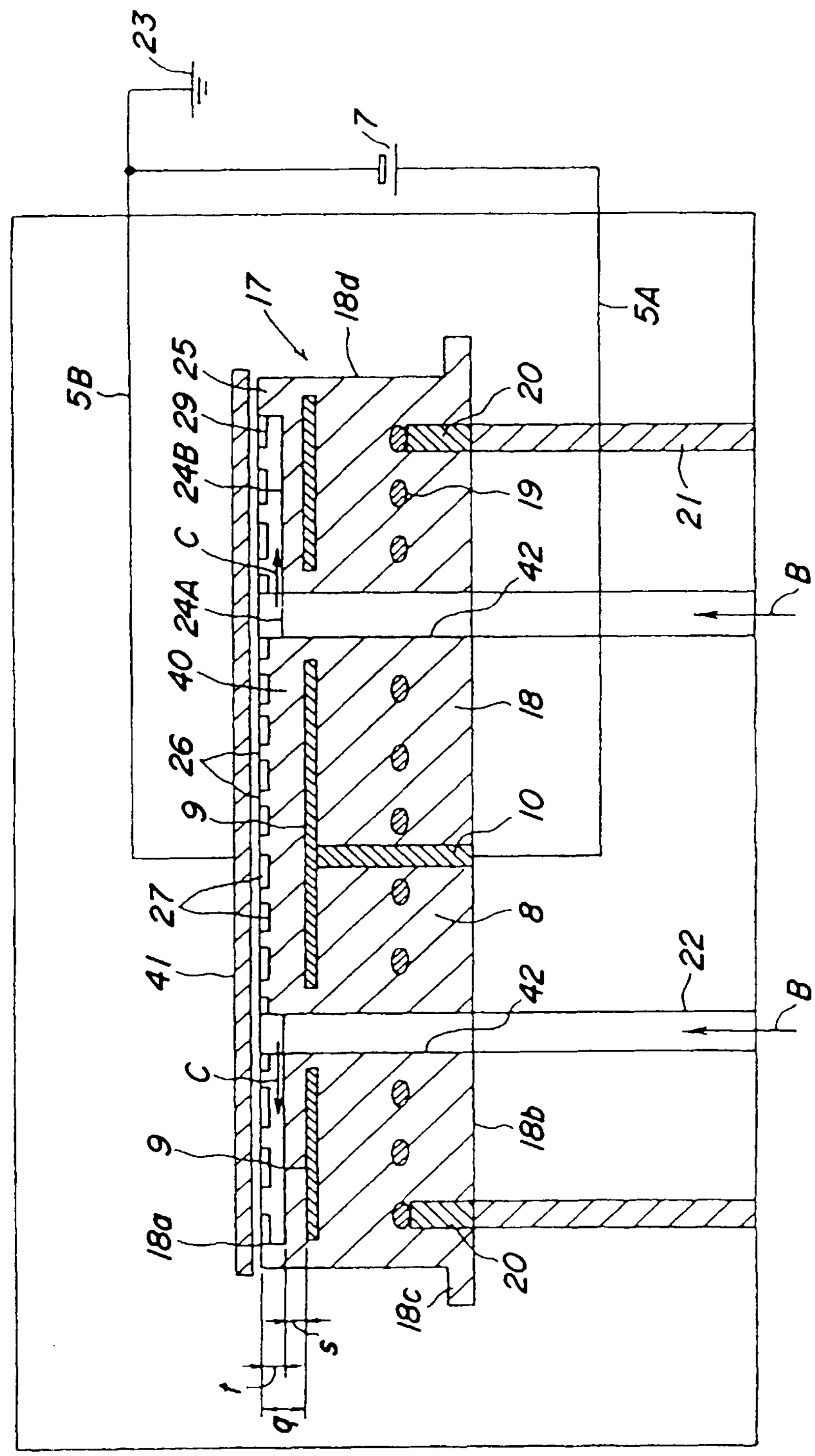


FIG.6


23
7
17
18d
5A
5B
25
29
24B
C
24A
40
26
9
27
41
20
19
21
42
B
18
10
8
22
18b
18a
18c
s
t
a

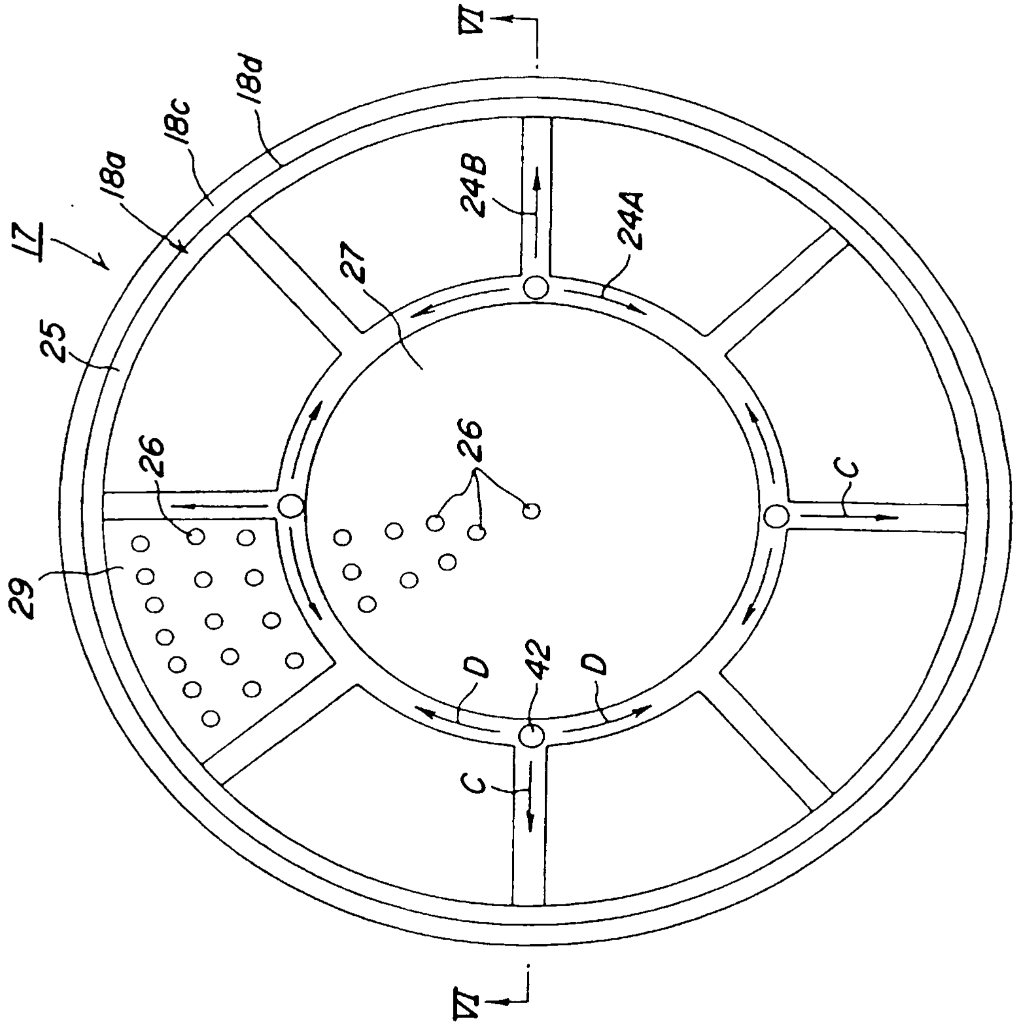
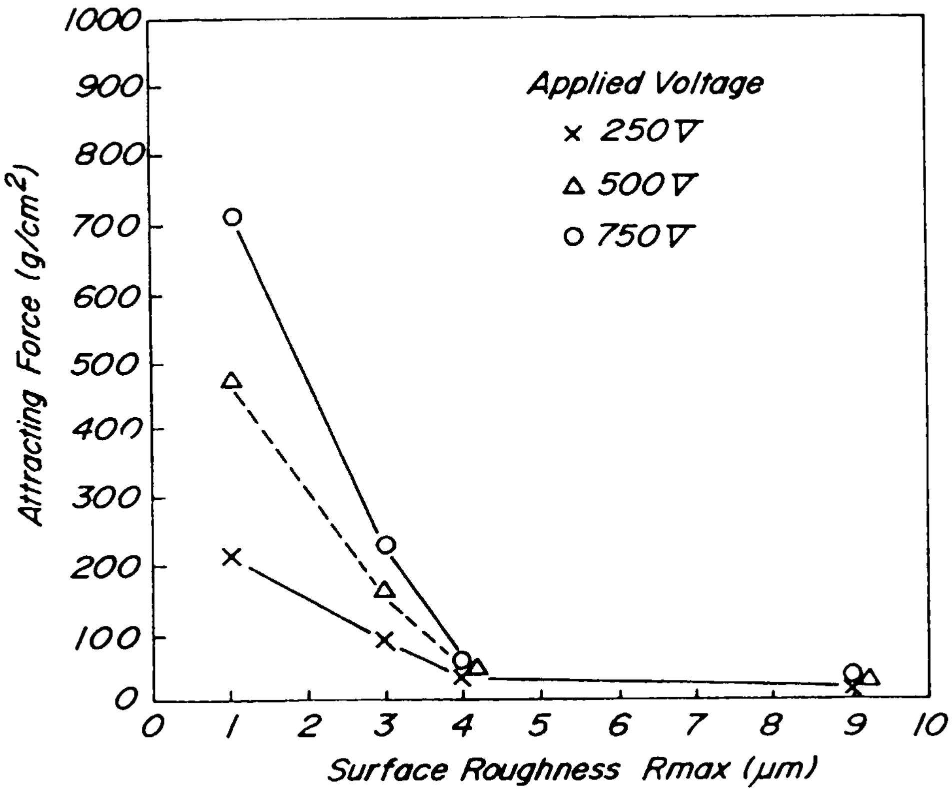


FIG. 7

FIG_8


Attracting Force (g/cm2)
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Surface Roughness Rmax (μm)
Applied Voltage
× 250V
△ 500V
○ 750V

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 791 956 A3

(12) **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:
05.11.1997 Bulletin 1997/45

(43) Date of publication A2:
27.08.1997 Bulletin 1997/35

(21) Application number: **96306414.2**

(22) Date of filing: **04.09.1996**

(51) Int Cl.⁶: **H01L 21/68**, H01L 21/00

(84) Designated Contracting States:
DE FR GB

(30) Priority: **06.09.1995 JP 229190/95**
20.08.1996 JP 218259/96

(71) Applicant: **NGK INSULATORS, LTD.**
Nagoya City Aichi Pref. (JP)

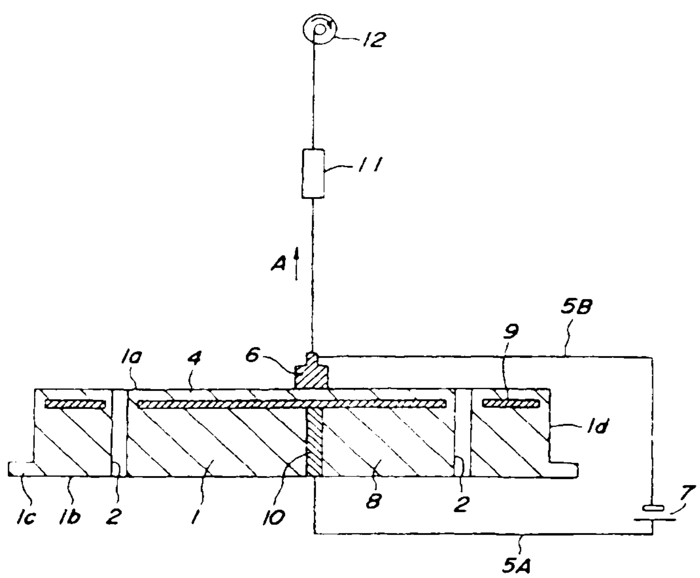
(72) Inventors:
- **Yamada, Naohito**
  Kasugai City, Aichi Pref. (JP)
- **Ohno, Masashi**
  Mizuho-Ku, Nagoya City, Aichi Pref. (JP)
- **Ushikoshi, Ryusuke**
  Tajimi City, Gifu Pref. (JP)

(74) Representative: **Paget, Hugh Charles Edward et al**
MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP (GB)

(54) **Electrostatic chuck**

(57) An electrostatic chuck for attracting an object to be treated, includes a substrate(1), an insulating dielectric layer (4) and at least one electrode (9) provided between the substrate and the insulating dielectric layer, wherein the above object is to be attracted onto the electrode via the insulating dielectric layer and an average thickness of the insulating dielectric layer (4) is not less than 0.5 mm and not more than 5.0 mm.

FIG.2



EP 0 791 956 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 30 6414

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	WO 95 14308 A (NGK INSULATORS LTD) 26 May 1995 & EP 0 680 075 A (NGK INSULATORS LTD) 2 November 1995 * page 9, line 46 - page 10, line 17; figures 4,5,7 * ---	1-5,9	H01L21/68 H01L21/00
X A	EP 0 506 537 A (SHINETSU CHEMICAL CO) 30 September 1992 * column 3, line 4 - line 31; claims 1-10 * * column 6, line 28 - line 34 * ---	1-3,9 4,5	
A	WO 92 20093 A (IBM) 12 November 1992 * page 6, line 29 - page 7, line 8; figure 1 * ---	1	
P,X	EP 0 693 774 A (IBM) 24 January 1996 * page 5, line 42 - page 6, line 28; figures 2A,2B,2C * ---	6-8	
E	EP 0 742 588 A (APPLIED MATERIALS INC ;IBM (US)) 13 November 1996 * column 8, line 7 - column 10, line 42; figures 1A,1B,2 * ---	8,9	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01L
A A	EP 0 601 788 A (APPLIED MATERIALS INC) 15 June 1994 * column 13, line 9 - column 15, line 57; figures 9-16 * * column 16, line 34 - line 42 * ---	6,8,9 1,2	
A	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 31, no. 1, 1 June 1988, pages 462-464, XP000119644 "ELECTROSTATIC WAFER HOLDER FOR WAFER COOLING DURING REACTIVE ION ETCHING" * the whole document * --- -/--	1,6,8,9	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	8 September 1997	Kirkwood, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

European Patent
Office

EP 96 306 414

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid,

namely claims:

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions,

namely:

See Sheet B.

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid,

namely claims:

☐ None of the further search fees has been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims,

namely claims:

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 30 6414

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 5 213 349 A (ELLIOTT JOE C) 25 May 1993 * the whole document * -----	6,8	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	8 September 1997	Kirkwood, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent
Office

EP 96 306 414.2 - B -

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims 1-5, 9 : Electrostatic chuck wherein the insulating dielectric has a thickness in the range 0.5-5.0mm.

2. Claims 6, 7, 8 : Electrostatic chuck having a gas-introducing hole and a gas-diffusing depression formed in the insulating dielectric layer and having a depth in the range 100µm to 5.0mm.

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 831 526 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
25.03.1998 Bulletin 1998/13

(51) Int Cl.6: H01L 21/68

(21) Application number: 97307330.7

(22) Date of filing: 19.09.1997

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV RO SI

(30) Priority: 19.09.1996 JP 247536/96

(71) Applicant: HITACHI, LTD.
Chiyoda-ku, Tokyo 101 (JP)

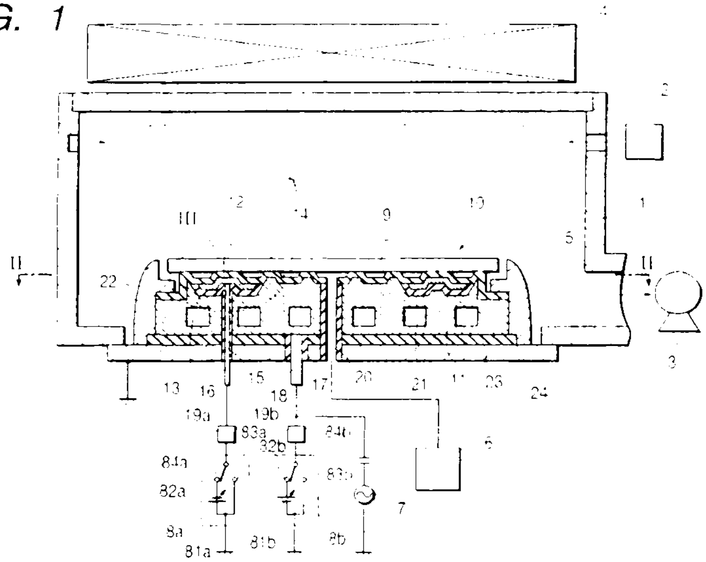
(72) Inventors:
- Kanno, Seiichiro
  Niihari-Gun, Ibaraki-Ken (JP)
- Usui, Tatehito
  Niihari-Gun, Ibaraki-Ken (JP)
- Yoshioka, Ken
  Hikari-Shi, Yamaguchi-Ken (JP)
- Kanai, Saburo
  Hikari-Shi, Yamaguchi-Ken (JP)
- Itou, Youichi
  Kudamatsu-Shi, Yamaguchi-Ken (JP)

(74) Representative: Paget, Hugh Charles Edward et al
MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP (GB)

(54) Electrostatic chuck, and method of and apparatus for processing sample using the chuck

(57) An electrostatic chuck (10) has a pair of electrodes (11,12) having different polarities; and a dielectric film (14), formed on top surfaces of the pair of electrodes, on which a sample is electrostatically attracted and held when a DC voltage is applied between the pair of electrodes; wherein amounts of electric charges stored on attracting portions of the dielectric film corresponding to the pair of electrodes directly before cessation of the DC voltage applied between the pair of electrodes are substantially equal to each other. With this chuck, the electric charges stored on the attracting portions of the dielectric film after cessation of the DC voltage can be eliminated due to the balance between the electric charges having different polarities. The electrostatic chuck thus achieves a significantly reduced residual attracting force of the sample.

FIG. 1



EP 0 831 526 A2

Description

BACKGROUND OF THE INVENTION

1 Field of the Invention

The present invention relates to an electrostatic chuck and a method of and an apparatus for processing a sample using the chuck and particularly to an electrostatic chuck suitable for electrostatically holding a sheet-like sample such as a semiconductor substrate or a liquid crystal substrate when the sample is processed or carried and a method of and an apparatus for processing a sample using the chuck.

2. Description of the Prior Art

As a bipolar type electrostatic chuck using a pair of electrodes having different polarities. there is known an electrostatically attracting apparatus having a pair of semi-circular or concentrically-circular shaped flat electrodes. for example from Japanese Patent Laid-open No. 64950/1982. According to the description of the above document by increasing a ratio between the area of the electrostatically attracting apparatus and the electrode area of a pair of flat electrodes. mounting a substance on the pair of flat electrodes through an insulator having a thickness of 50 to 200 μm. and electrostatically attracting the substance by applying a voltage between the flat electrodes. it is possible to apply the electrostatically attracting apparatus to both a conductive substance and a conductive substance whose surface is covered with a thin insulating film. to make stronger the attracting force. and to simplify the structure of the apparatus. The document also describes that the attracting force is maximized when the areas of the pair of positive and negative electrodes are equal to each to other. Also another bipolar type electrostatic chuck is disclosed in Japanese Patent Laid-open No. 120329/1994

The method of holding a sample. for example. a wafer using such an electrostatic chuck has advantages that: (1) since a surface of a wafer to be processed is not mechanically contacted with the chuck. the wafer can be prevented from being contaminated by abrasive particles and the like: and (2) since the entire back surface of a wafer is fixedly attracted on the chuck. the camber of the wafer can be corrected so that the contact of the wafer with an attracting surface of the chuck becomes more reliable when the wafer is finely processed by etching or the like. to improve the thermal conductivity of the wafer. thereby facilitating the temperature control of the wafer For these reasons. the electrostatic chuck is being extensively used as a sample stage (or called simply as "electrode") of a dry etching apparatus or a plasma processing apparatus such as a CVD apparatus.

As a bipolar type electrostatic chuck used for a plasma processing apparatus. there is known an electrostatically attracting apparatus for example from Japanese Patent Publication No 44747/1982 The document describes that a larger attracting force can be obtained during plasma discharge by making larger the area of a positive electrode than that of a negative electrode and that the attracting force in the case of generation of no plasma is maximized when a ratio between the areas of the positive and negative electrodes is set at 1

Another disadvantage of the electrostatic chuck will be described below. In general to remove a wafer from the electrostatic chuck after termination of processing the wafer bar-like supports (generally called "pushers" or "lift pins") are used to be lifted from the interior of the electrostatic chuck for pushing up the wafer therefrom. The mechanism of the bar-like supports is known. for example from USP 4 565. 601 or Japanese Patent Laid-open No. 252253/1994 However. in the case where there exists a residual attracting force between an electrostatic chuck and a wafer. if a wafer is forcibly peeled from the electrostatic chuck by applying a strong force against the residual attracting force. there arises a problem that the wafer is cracked or undergoes abnormal discharge too large to destroy devices of the wafer

To cope with the disadvantages due to a residual attracting force. various method for eliminating an electric charge stored on an electrostatic chuck have been proposed. For example. a method of eliminating an electric charge stored on an electrostatic chuck upon removal of a sample from the chuck is known from USP 5.117.121. wherein a residual attracting force eliminating voltage. having a polarity reversed to that of an attracting voltage and being higher than the attracting voltage. is applied between electrodes of the chuck. Another method of eliminating an electric charge stored on an electrostatic chuck is known from Japanese Patent Laid-open No 185773/1983. wherein a DC voltage for generating an electrostatically attracting force is turned off. and thereafter a radio frequency power for generating a plasma is turned off. Besides these. there are known various methods of removing a sample from an electrostatic chuck. for example. from Japanese Patent Laid-open Nos. 112745/1989 and 247639/1992.

SUMMARY OF THE INVENTION

The prior art electrostatic chucks described in the above document. Japanese Patent Laid-open No. 64950/1982 and Japanese Patent Publication No. 4474/1982 have failed to examine a residual attracting force.

Namely. in the case where the temperature of a wafer as a sample is required to be controlled at a specific value during processing of the wafer. for example. at a plasma processing step. a heat transfer gas is supplied between the back surface of the wafer and an electrostatic chuck. For this purpose. the electrostatic chuck has a structure in which a wafer mounting surface of the

chuck is provided with a dispersion groove (or called "a gas groove") for uniformly supplying a heat transfer gas. An electrostatic chuck used for holding a wafer subjected to plasma processing is known, for example, from Japanese Patent Laid-open No. 86382/1995, wherein a wafer mounting surface of the chuck has a recess for reducing a contact area between the wafer mounting surface and the wafer, thereby suppressing adhesion of contaminants on the wafer. With respect to the dispersion groove or recess, various patterns have been developed. In the case where a groove or recess is provided in a wafer mounting surface of an electrostatic chuck as described above, attracting areas on the positive and negative electrode sides change depending o the size and shape of the dispersion groove or recess, so that a residual attracting force is generated.

Further, even in the case where an electrostatic chuck is used during processing by plasma, amounts of electric charges stored on attracting surfaces on the positive electrode side and the negative electrode are different from each other by generating a self-bias voltage due to plasma and applying a radio frequency bias, so that a residual attracting force is generated.

As a result, even the bipolar type electrostatic chuck requires a step of eliminating an electric charge stored on the chuck for removing a residual attracting force, so that there arises a problem in terms of lowering the throughput in carrying wafers. Another problem is that since an electric charge remains in a dielectric film constituting an attracting surface of the electrostatic chuck, the attracting surface is liable to attract contaminants which in turn adhere on the back surface of a new sample attracted on the attracting surface. In particular, when a wafer is processed using a CVD apparatus which generates deposits having electric charges, such a problem becomes significant.

Further, the method of eliminating a residual attracting force, as described in the above document, USP 5,117,121, requires the step of eliminating an electric charge stored on the chuck by newly applying a reversed voltage. This causes a problem in terms of lowering the throughput in carrying a sample. Also, if the reversed voltage becomes excessively larger, there arises another problem that an electrostatically attracting force is produced again, to thereby generate a residual attracting force. Besides, in the method of eliminating a residual attracting force, as described in the above document, Japanese Patent Laid-open No. 185773/1983, since after stopping of supply of the DC voltage for electrostatic attraction, supply of the radio frequency power for generating a plasma is stopped, the time required for eliminating the electric charge must be made longer. This causes a problem in terms of lowering the throughput in carrying a wafer. In the case of supplying a heat transfer gas to the back surface of a sample simultaneously with electrostatic attraction, supply of the transfer gas is usually stopped upon stopping of supply of the DC voltage for electrostatic attraction. As a result, the temperature of the sample is increased and thereby plasma is continued to be produced, to proceed processing of the sample, thereby exerting adverse effect on the sample, the processing of which should have been terminated.

Additionally, in a plasma processing apparatus, generally, a radio frequency voltage is applied to a sample stage for controlling an incident energy of ions in a plasma against the sample by means of a bias voltage generated at the sample stage. When such a plasma processing apparatus uses a bipolar type electrostatic chuck, it is difficult to equally apply the bias voltage to the sample resulting from the electrode structure of the chuck, as compared with the case using a monopole type electrostatic chuck. This possibly exerts adverse effect on uniform processing of the sample.

In view of the foregoing, the present invention has been made, and a first object of the present invention is to provide an electrostatic chuck capable of reducing a residual attracting force to a value in a substantially practically usable range.

According to the present invention, there is provided an electrostatic chuck including: a pair of electrodes having different polarities; and a dielectric film, formed on top surfaces of the pair of electrodes, on which a sample is electrostatically attracted and held when a DC voltage is applied between the pair of electrodes; wherein amounts of electric charges stored on attracting portions of the dielectric film corresponding to the pair of electrodes directly before stop of supply of the DC voltage applied between the pair of electrodes are substantially equal to each other.

Another object of the present invention is to provide a sample processing method capable of reducing a stand-by time upon removal of a sample from an electrostatic chuck for improving the throughput.

According to the present invention, there is provided a sample processing method including the steps of: electrostatically attracting and holding a sample on an electrostatic chuck including a pair of electrodes having different polarities and a dielectric film formed on top surfaces of the pair of electrodes, by applying a DC voltage between the pair of electrodes; and processing the sample electrostatically attracted and held on the chuck through the dielectric film; wherein amounts of electric charges stored on attracting portions of the dielectric film corresponding to the pair of electrodes directly before stop of supply of the DC voltage applied between the pair of electrodes after termination of processing the sample, are substantially equal to each other, so that the electric charges stored on the attracting portions of the dielectric film after stop of supply of the DC voltage are reduced or eliminated due to the balance therebetween, whereby the sample is removable from the sample mounting surface, e.g. without any additional step.

A further object of the present invention is to provide a sample processing apparatus capable of reducing a stand-by time upon removal of a sample from an elec-

trostatic chuck for improving the throughput

In a third aspect of the present invention, there is provided a sample processing apparatus for processing a sample electrostatically attracted and held on an electrostatic chuck, the electrostatic chuck including an electrostatic chuck including a pair of electrodes having different polarities, and a dielectric film formed on top surfaces of the pair of electrodes on which a sample is electrostatically attracted and held when a DC voltage is applied between the pair of electrodes wherein a recess being not in contact with the back surface of the sample is formed in a surface of the dielectric film on which the sample is disposed; and amounts of electric charges of different polarities stored on attracting portions of the surface of the dielectric film excluding the recess are equal to each other.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a vertical sectional view of one example of a sample processing apparatus using an electrostatic chuck as a first embodiment of the present invention;

Fig. 2 is a plan view taken on line II-II of Fig. 1, showing the electrostatic chuck;

Fig. 3 is a view showing the details of a portion III of Fig. 1;

Fig. 4 is a diagram showing potentials of a wafer and electrodes of the electrostatic chuck shown in Fig. 1;

Fig. 5 is a time chart showing steps of attracting a wafer, processing the wafer, and eliminating electric charges in the case of processing using the apparatus shown in Fig. 1;

Fig. 6 is a graph showing a relationship between a residual attracting force and a time elapsing from stop of supply of a radio frequency voltage to plasma extinction in the case of processing using the apparatus shown in Fig. 1;

Fig. 7 is a vertical sectional view of the electrostatic chuck portion shown in Fig. 1;

Fig. 8 is a graph showing a load applied to a wafer upon removal of the wafer from the electrostatic chuck shown in Fig. 7;

Figs. 9(a) to 9(c) are vertical sectional views showing other electrode arrangements of the electrostatic chuck shown in Fig. 1;

Fig. 10 is a vertical sectional view showing another connection example of a DC power supply for the electrostatic chuck shown in Fig. 1;

Fig. 11 is a diagram showing potentials of a wafer and electrodes of the electrostatic chuck shown in Fig. 10;

Fig. 12 is a vertical sectional view showing a further connection example of a DC power supply for the electrostatic chuck shown in Fig. 1;

Fig. 13 is a diagram showing potentials of a wafer and electrodes of the electrostatic chuck shown in Fig. 12;

Fig. 14 is a perspective view showing an electrostatic chuck as a second embodiment of the present invention;

Fig. 15 is a plan view of the electrostatic chuck shown in Fig. 14;

Figs. 16(a) to 16(c) are diagrams each showing a relationship between a gap and an attracting force upon electrostatic attraction;

Fig. 17 is a graph showing a change in resistivity of a dielectric film of the electrostatic chuck shown in Fig. 14 depending on the temperature;

Fig. 18 is a typical view showing a third embodiment using the electrostatic chuck of the present invention, showing a state in which contaminants adhering on a dielectric film are transferred on a dummy wafer;

Fig. 19 is a diagram showing another example of removal of contaminants shown in Fig. 18, showing a DC voltage applied to the electrostatic chuck in such a manner as to be alternately changed in polarity;

Fig. 20 is a view showing a sample processing apparatus as a fourth embodiment using the electrostatic chuck of the present invention, in which the electrostatic chucks are used for all wafer holding portions of the apparatus;

Fig. 21 is a view showing the details of a wafer holding portion of a carrying robot in the apparatus shown in Fig. 20;

Fig. 22 is a diagram showing an equivalent circuit of the electrostatic chuck;

Fig. 23 is a graph showing a relationship between a volume resistivity of a ceramic material and an applied voltage;

Figs. 24(a) to 24(c) are diagrams each showing an attracting action and an electric charge eliminating action in the equivalent circuit shown in Fig. 22; and

Fig. 25 is a graph showing a relationship between a residual attracting force and a leaving time using an attracting area ratio as a parameter.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Prior to description of the preferred embodiments, there will be described the cause for generation of a residual attracting force and the effect of the present invention with reference to Figs. 22 to 25. Fig. 22 shows a simple equivalent circuit of an electrostatic chuck in which a ratio between areas of actual attracting portions of two electrodes (for example, electrodes A and B) is set at 2.8, that is, electrode A side : electrode B side = 2.8 (152.5 cm^2) : 1 (54 cm^2). The equivalent circuit of the electrostatic chuck being actuated to attract a wafer will be briefly described. In the equivalent circuit shown in Fig. 22, a parallel circuit including an electrostatic capacity Ca of the electrode A and a resistance Ra of a

dielectric film formed on the electrode A is connected in series to a parallel circuit including an electrostatic capacity Cb of the electrode B and a resistance Rb of a dielectric film formed on the electrode B through a resistance Rw (sufficiently smaller than each of Ra and Rb) of the wafer.

Letting Va. Vb be potential differences finally generated between the electrodes A and B and the wafer when a voltage of 400 V is applied between the electrodes A and B in such a state. the following equations are given in a stable state.

$$Va + Vb = 400 \quad (1)$$

$$Ra : Rb = Va : Vb \quad (2)$$

In the case of using the dielectric film made from a ceramic material. however. the volume resistivity thereof is changed depending on the applied voltage. as shown in Fig. 23. Accordingly. letting V be the applied voltage. the volume resistivity of the dielectric film of the electrostatic chuck used for the present invention is expressed by the following equation:

$$\text{volume resistivity} = 1 \times 10^{(11.953-0.000764\ V)} \quad (3)$$

Since the resistance of the actual attracting portion of the dielectric film formed on each electrode can be calculated from the volume resistivity of the dielectric film. the potential difference between each electrode and the wafer can be obtained on the basis of the equations (1) to (3). In this example. the potential difference Va between the electrode A and the wafer is 126 V. and the potential difference Vb between the electrode B and the wafer is 274 V. Incidentally. as for the dielectric film. the electrostatic capacity is obtained by dividing the product of the dielectric constant and the area by the thickness. Here, assuming that the relative dielectric constant of the ceramic forming the dielectric film is 5. the electrostatic capacity of thee dielectric film is determined. Thus. the amount of an electric charge stored on the dielectric film can be calculated on the basis of the electrostatic capacity of the dielectric film thus determined and the potential difference on the dielectric film obtained using the equations (1) to (3). In the actual attraction. however. there exists a space represented by a surface roughness between the wafer and the dielectric film. Such a space may be regarded as a substantially vacuum space in a vacuum chamber even if there exists a heat transfer gas. Now in this example. assuming that the space distance is about 3 μm and the thickness of the dielectric film is 300 μm. the space distance is one-hundredth of the thickness of the dielectric film. As a result. even if the dielectric constant of the space is one-fifth of that of the dielectric film. the electrostatic capacity of the space becomes about 20 times that of the dielectric film. For this reason. the electrostatic capacity of the space is used in place of that of the dielectric film for the above-described calculation. The results thus calculated are summarized as follows: namely. the electrode A has an area of 152.5 cm^2. capacity of 46 nF. potential difference with wafer of 126 V. and amount of electric charge of 5.8×10^{-6} coulomb [C]; and the electrode B has an area of 54 cm^2. capacity of 16 nF. potential difference with wafer of 274 V. and amount of electric charge of 4.4×10^{-6} coulomb [C]. From these results, it becomes apparent that there is a difference between the amounts of the electric charges stored on the actual attracting portions on the electrodes A and B.

Figs. 24(a) to 24(c) are typical diagrams showing changes in amounts of electric charges stored in capacity components when a DC power supply is turned off from an attracting state. In the attracting state shown in Fig. 24(a). electric charges are unbalancedly stored on a dielectric film formed on electrodes A and B in large amounts. When application of a DC voltage is stopped. the electric charge stored on the dielectric film formed on the electrode B is quickly eliminated by way of circuits 1 and 2 because the resistance of a wafer is sufficiently smaller than the resistance of the dielectric film, as shown in Fig. 24(b). Besides. the electric charge remaining on the dielectric film on the electrode A is eliminated by way of the circuit 3 or 4 as shown in Fig. 24 (c): however. the elimination of the electric charge takes a long time because the circuit 3 or 4 has a large value of the resistance Ra or Rb. that is. it has a large discharge time constant. Such a remaining electric charge becomes the cause for generation of a residual attracting force.

On the other hand. in the case where a ratio between areas of actual attracting portions of a dielectric film on two electrodes is 1 : 1 as in the embodiment of the present invention. since the attracting portions of the dielectric film on the two electrodes have the same resistance and also have the same potential difference with a wafer. electric charges stored on the attracting portions are equal to each other. Accordingly. when application of a DC voltage is stopped. the electric charges on the attracting portions is eliminated only by way of the circuits 1 and 2 shown in Fig. 24(a). so that it takes a short time to eliminate the electric charges and thereby no residual attracting force remains on the attracting portions.

Fig. 25 is a graph showing residual attracting force generating states when a ratio between areas of attracting portions of a dielectric film formed on two electrodes is changed. In this figure, the abscissa indicates the time elapsed after cutting off a DC power supply. and the ordinate indicates the residual attracting force. From the results shown in Fig. 25. it is revealed that the residual attracting force is not generated when the area ratio between the actual attracting portions on the two electrodes is 1 : 1. however. it becomes larger with the in-

creasing area ratio.

Accordingly, in an electrostatic chuck having the configuration that a ratio between areas of wafer attracting portions of a dielectric film formed on two electrodes as in this example, a residual attracting force is little generated and it takes a short time to eliminate the electric charges stored on the wafer attracting portions. A sample processing apparatus including the electrostatic chuck is also advantageous in improving the throughput of the apparatus and preventing a wafer from being broken when the wafer is pushed up by lift pins or the like after termination of processing the wafer.

Hereinafter, a first embodiment of the present invention will be described with reference to Figs. 1 to 8.

Fig. 1 shows one example of a sample processing apparatus using an electrostatic chuck as the first embodiment of the present invention. The sample processing apparatus is represented by an etching apparatus, a processing apparatus using plasma such as a film formation apparatus, or a vacuum processing apparatus not using plasma such as an ion injection apparatus. In this embodiment, description will be made by example of a plasma processing apparatus.

Referring to Fig. 1, there is shown a vacuum chamber 1 to which a gas supply unit 2 and an evacuation unit 3 are connected. The vacuum chamber 1 is provided with a plasma generating unit 4 for generating a plasma 5 in the vacuum chamber 1. In the vacuum chamber 1, is provided a sample stage on which a sample to be processed by the plasma 5, for example, a substrate 9 such as a semiconductor substrate (or wafer) or a liquid crystal substrate is mounted. The sample stage comprises an electrostatic chuck 10.

The electrostatic chuck 10 is composed of an inner electrode 11, a ring electrode 12, an insulating film 13, and an insulating film (or dielectric film) 14 for electrostatic attraction. A coolant passage 21 is formed in the electrode 11. A ring-shaped recess in which the electrode 12 is to be formed, is formed in the top surface of the electrode 11. The electrode 12 is formed into a ring-shape. The electrode 11 is made from a conductive material such as an aluminum alloy. In the recess formed in the top surface of the electrode 11, is provided the electrode 12 through the insulating film 13. The insulating film 13 is formed from alumina by thermal spraying, and the electrode 12 is formed from tungsten by thermal spraying. The insulating film 13 is interposed between the electrodes 11 and 12 for directly insulating the electrodes 11 and 12 from each other. On the surfaces of the electrodes 11 and 12, is formed the insulating film 14 for electrostatic attraction. The insulating film 14 is formed from alumina by thermal spraying. In addition, the insulating film 13 is made from a material having a resistance high than that of the insulating film 14 for electrostatic attraction. This is because an electric circuit for electrostatic attraction is formed through the insulating film 14.

A lead wire 18 is connected to the inner electrode 11 for applying a voltage thereto, and a lead wire 16 is connected to the ring electrode 12 for applying a voltage thereto. The lead wire 16 is connected to the ring electrode 12 by way of a through-hole formed of an insulating sleeve 15 in the inner electrode 11. The lead wire 16 is electrically insulated from the inner electrode 11 by the insulating sleeve 15. The lead wires 16 and 18 are connected through low pass filters 19a and 19b to power supplies 8a and 8b for electrostatic attraction, respectively. A negative voltage is applied from the DC power supply 8a to the ring electrode 12, and a positive voltage, which has the same absolute value as that of the negative voltage applied to the ring electrode 12, is applied from the DC power supply 8b to the inner electrode 11. The electrodes 11 and 12 can be earthed by turning terminals 82a and 82b to terminals 83a and 83b using switches 84a and 84b, respectively. The inner electrode 11 and the ring electrode 12 are electrically insulated from the substrate 9 by the insulating film 14 for electrostatic attraction. Accordingly, by applying positive and negative voltages from the power supplies 8a and 8b to the inner electrode 11 and the ring electrode 12, a DC circuit is formed through the substrate 9 and thereby electric charges are stored, so that the substrate 9 can be electrostatically attracted on the top surfaces of the electrodes 11 and 12.

For connection of the lead wire 16 to the ring electrode 12, as shown in Fig. 3, a flange is provided on the upper portion of the insulating sleeve 15, and an electrode core 161 is provided in the upper space of the flange while a socket 162 is provided in the lower space of the flange. The socket 162 is fixed to the flange in a state being screwed in the electrode core 161. The lead wire 16 is inserted in the socket 162 to be thus connected thereto. The ring electrode 12 is formed by thermal spraying in a state that the electrode core 161 is fixed in the flange of the insulating sleeve 15. Thus, the electrode core 161 can be easily connected to the ring electrode 12. Here, the electrode core 161 is made from the same material, tungsten as that of the ring electrode 12 so as to ensure the connection with the ring electrode 12. In addition, the lead wire 18 can be easily connected to the inner electrode 11 by a method wherein a female thread portion (not shown) is formed in the inner electrode 11 and a male thread portion is formed at the leading end portion of the lead wire 18, whereby the male thread portion of the lead wire 18 is screwed in the female thread portion of the inner electrode 11.

A central portion of the inner electrode 11 is pierced to form a through-hole 20 in which the insulating sleeve is provided. The through-hole 20 is used for introducing a heat transfer gas to the back surface of the substrate electrostatically attracted on the electrostatic chuck 10. Here, the insulating film 14 for electrostatic attraction is formed by thermal spraying and is finally finished by polishing into a flat shape having a specific thickness. The use of the insulating film 14 formed by thermal spraying allows a groove to be easily formed in the surface of the

inner electrode 11 or ring electrode 12 after formation of the insulating film 14 by previously machining the surface of the electrode 11 or 12 to form a recess (not shown). This facilitates such a electrode design as to provide a gas dispersion groove in the surface of the electrode

The gas dispersion groove (or gas groove) is provided in the surface of the electrode for supplying a heat transfer gas (for example helium gas) to the back surface of a substrate to be processed thereby controlling the temperature of the substrate or adjusting a heat transfer characteristic for making uniform a substrate temperature distribution. Here. as shown in Fig. 2. there is provided a gas dispersion groove composed of a plurality of circumferentially extending groove components partially connected to each other in the radial direction. The gas dispersion groove has a depth of 0.3 mm.

An attracting surface of the insulating film 14. which has no dispersion groove and is brought in direct-contact with the substrate 9. has attracting surfaces Al to A4. B1 to B4. and D corresponding to the inner electrode 11: and attracting surfaces C1 to C4 corresponding to the ring electrode 12. The area relationship of these attracting surfaces is set such that the total area of the attracting surfaces A1 to A4. B1 to B4. and D is equal to the total area of the attracting surfaces C1 to C4.

The insulating film 13. ring electrode 12. and insulating film 14 are formed by thermal spraying to thicknesses of 0.3 mm, 0.1 mm. and 0.4 mm. respectively. The contact surface of the insulating film 14 with the substrate 9 is polished to a thickness of 0.3 mm. The total thickness of the films formed on the inner electrode 11 by thermal spraying is 0.8 mm or less. That is. while the total thickness of the films formed on the inner electrode 11 by thermal spraying is maximized at a portion of the ring electrode 12. even such a maximized total thickness is as very thin as 0.8 mm. Accordingly the presence of the insulating films exerts only a negligible effect on application of a radio frequency voltage to the entire inner electrode 11. and thereby it does not affect processing of the substrate 9.

The electrostatic chuck 10 is mounted on the bottom surface of the vacuum chamber 1 through an earth plate 24. The inner electrode 11 is mounted on the earth plate 24 through an insulating plate 23. To prevent leakage of a heat transfer gas from the through-hole 20 provided in the central portion of the inner electrode 11 when the heat transfer gas is supplied into the through-hole 20. contact portions with the through-hole 20 are sealed. The inner electrode 11. insulating plate 23. and earth plate 24 are fastened to each other with bolts (not shown).

A cover 22 is provided around the outer surface of the inner electrode 11 in such a manner that the outer peripheral portion thereof is smoothly tilted inward in the upward direction. When ions in a plasma are irradiated from top to bottom. the cover 22 formed into such a shape has no shady portion. so that reaction products. if deposited on the cover 22 during plasma etching can be easily removed by exposing the cover 22 to a cleaning plasma. As a result. it is possible to easily reduce contaminants.

A radio frequency power supply 7 as well as the power supply 8b for electrostatic attraction is connected to the inner electrode 11. The radio frequency power supply 7 is provided for applying a radio frequency bias voltage to the inner electrode 11. To prevent occurrence of abnormal discharge between the inner electrode 11 and the earth plate 24. the diameter of the insulating plate 23 is set to be larger than that of the inner electrode 11 and to be smaller than that of the earth plate 24 for preventing the inner electrode 11 from directly facing to the earth plate 24. With this configuration. it is not required to provide a separate insulating member around the outer surface of the inner electrode 11. That is. the cover 22 can serve as such an insulating member.

The temperature of the substrate 9 shown in Fig. 1 is controlled on the basis of the temperature of a coolant flowing in the coolant passage 21 provided in the inner electrode 11. Specifically, the temperature of the inner electrode 11 is controlled on the basis of the temperature of the coolant. and then the temperature of the substrate 9 is controlled by heat transfer from the cooled inner electrode 11 through the insulating film 14 and by the heat transfer gas supplied on the back surface of the substrate 9. In this embodiment. although the coolant passage 21 is provided only in the inner electrode 11. the temperature of the ring electrode 12 is also controlled by heat transfer from the inner electrode 11 through the thin insulating film 13. Accordingly, the coolant is not required to be supplied to the ring electrode 12, that is. it is sufficient for cooling the electrode 11 and 12 to provide the coolant passage 21 only in the inner electrode 11, thereby simplifying the cooling mechanism.

In the plasma processing apparatus having the above configuration. a negative voltage is applied to the ring electrode 12. and a positive voltage. which has the same absolute value as that of the voltage applied to the ring electrode 12. is applied to the inner electrode 11. With such application of the positive and negative voltages to the electrodes 11 and 12. the electrode potentials shown in Fig. 4 are obtained

Fig. 4 shows potentials of a substrate and electrodes of an electrostatic chuck when the substrate electrostatically attracted on the chuck is exposed to a plasma. In the state shown in the figure. the plasma is generated by a power supplying means provided separately from power supplies for applying voltages to the electrodes of the electrostatic chuck. Specifically. in the example shown in Fig. 4. there are shown potentials of the substrate 9. ring electrode 12. and inner electrode 11 in a state that the substrate 9 is electrostatically attracted on the electrostatic chuck in a condition that a voltage of -250 V is applied to the ring electrode 12 and a voltage of +250 V is applied to the inner electrode 11. In the electrostatic chuck thus connected to the DC power sup-

plies the potential of the substrate 9 (wafer) attracted on the chuck is 0 V. Accordingly, even if the potential of the wafer is changed from 0 V to about -20 V by generation of a plasma, there occurs only a small change in potential difference between the wafer and each electrode. As a result, the change in electric charge stored between the wafer and each electrode is also small.

In the electrostatic chuck according to this embodiment, in which the attracting areas corresponding to the positive and negative electrodes are equal to each other and the power supplies are connected to the chuck such that DC voltages different in polarity and equal in absolute value are applied to the electrodes for electrostatic attraction, a residual attracting force of the chuck in a state that only a plasma is generated is very small. As a result, the effect of the residual attracting force on removal of the wafer from the electrostatic chuck is substantially negligible. Also, as the DC voltages are continued to be applied from the power supplies for electrostatic attraction after plasma extinction, the potential of the wafer is returned into the original one with no generation of plasma. Thus, the potential difference between the wafer and each electrode becomes zero. As a result, in the electrostatic chuck having the attracting areas equal to each other, amounts of electric charges stored on the attracting areas are equal to each other in accordance with the principle described with reference to Figs. 22 to 25, electric charges remaining on the attracting areas corresponding to the electrodes are eliminated when the DC power supplies are turned off. In other words, the electrostatic chuck in this embodiment has an effect of eliminating generation of a residual attracting force.

On the other hand, in some cases, to promote processing of a substrate, a radio frequency voltage is applied to a sample stage for generating a bias potential (generally, about -300 V or less) at the substrate. In this case, as shown in Fig. 4, the potential differences between the substrate and the electrodes are changed, so that there occurs a large difference between amounts of electric charges stored on the attracting areas corresponding to the electrodes. Even in this case, however, a residual attracting force can be reduced to zero by applying DC voltages to the electrodes for a specific time after plasma extinction. Further, by stopping application of the radio frequency voltage during generation of plasma and then keeping generation of plasma for a specific time, the potential difference between the wafer and each electrode can be reduced to that in the above-described plasma generation state without application of the radio frequency voltage, that is, to a value within the negligible range of about -20 V or less. In this state in which the potential difference between the wafer and each electrode is about 40 V, an attracting force is significantly small, and accordingly, when being pushed up using lift pins, the substrate is not cracked. Consequently, in elimination of a residual attracting force in the case where a radio frequency voltage is applied to a sample stage to promote processing a wafer, the residual attracting force can be effectively eliminated by adjusting a time from stop of supply of the radio frequency voltage to plasma extinction and a time from plasma extinction to stop of supply of the DC voltages for electrostatic attraction.

In addition, when a radio frequency voltage is applied as shown in Fig. 4, the potential difference between the wafer and the inner electrode (positive electrode) is made larger and the potential difference between the wafer and the ring electrode (negative electrode) is made smaller. In the electrode configuration of this embodiment, since the inner electrode forming the attracting components positioned at the outer peripheral portion and the central portion of the electrostatic chuck is applied with a positive electrode, the electrostatic chuck can strongly hold the outer peripheral portion and the central portion of the wafer. This is effective to more preferably suppress leakage of a heat transfer gas from the outer peripheral portion of the wafer during plasma processing. Further, such an electrode configuration is effective to cool the central portion of the wafer more strongly because the central portion of the wafer is strongly attracted on the chuck. In the case where the central portion of the wafer is not intended to be strongly cooled, the heat transfer efficiency at the gas groove portion corresponding to the central portion of the wafer by enlarging the area and depth of the gas groove portion. In this case, with respect to the attracting portion corresponding to the ring electrode 12, the area thereof is made smaller and also the depth of the gas groove portion is made smaller, as compared with the attracting portion of the inner electrode 11.

Next, there will be a procedure of attracting a substrate, starting plasma processing, terminating plasma processing, and eliminating electric charges in the substrate in this order with reference to a time chart shown in Fig. 5. First, a substrate is carried into the vacuum chamber 1 by a carrier (not shown). After the substrate is placed on the electrostatic chuck 10, a DC voltage is applied between the positive and negative electrodes 11 and 12 for attracting the substrate, and then a heat transfer gas is introduced in the gas groove provided in the surface of the insulating film (dielectric film) 14. At this time, a processing gas for processing the substrate has been already introduced into the vacuum chamber 1 by the gas supply unit 2 and kept at a specific pressure. Then, an energy (for example, microwave electric field, radio frequency electric field or the like) for generation of a plasma is introduced into the vacuum chamber 1 by the plasma generating unit 4. A plasma is thus generated into the vacuum chamber 1. Next, a radio frequency voltage for generating a bias voltage at the substrate is applied. It is to be noted that the necessity of applying a radio frequency voltage is dependent on the process used, and that in the case of applying a radio frequency voltage, application and stopping of the radio frequency voltage is performed during stable generation of plasma

for matching of impedance. The plasma extinction is performed by stopping introduction of the energy for generating the plasma, simultaneously with termination of processing the wafer by plasma. In addition, supply of the radio frequency voltage is stopped before plasma extinction. Here, plasma extinction is performed after an elapse of four seconds since stopping of the radio frequency voltage. This eliminates, as described above, an unbalance between electric charges stored on attracting portions of the insulating film (dielectric film) formed on the electrodes 11 and 12 during plasma processing. After termination of processing the substrate, supply of the heat transfer gas, which becomes unnecessary, is stopped and the heat transfer gas remaining in a dispersion groove and a gas supply passage (both, not shown) is exhausted. Then, the wafer is removed from the electrostatic chuck and carried; however, prior to removal of the wafer, the processing gas, which is usually composed of a harmful gas, must be sufficiently exhaust. In this embodiment, the exhaust of the processing gas is performed for about ten seconds, and elimination of electric charges (residual attracting force) stored on the electrostatic chuck is terminated during the time required for exhaust of the processing gas. Specifically, introduction of the heat transfer gas and the processing gas is stopped after an elapse of one second since plasma extinction, and exhaust of the heat transfer gas remaining in the dispersion groove is performed for 0.5 second. After that, supply of the DC voltage for electrostatic attraction is terminated after an elapse of three seconds since plasma extinction. This operation of keeping supply of the DC voltage for three seconds after plasma extinction, as described above, reduces the unbalance between the electric charges stored on the attracting portions of the insulating film (dielectric film) on the electrodes 11 and 12, except for the unbalance between the electric charges having been eliminated by keeping generation of the plasma after stopping of the radio frequency voltage. Thus, since the amounts of the electric charges on both the electrodes are balanced, the electric charges polarized on both the electrodes are quickly extinguished for about two or three seconds after stopping of the DC voltage. Consequently, the substrate can be carried directly after termination of exhausting the processing gas. After carrying the substrate from the vacuum chamber, a new substrate to be processed is carried into and processed in the vacuum chamber in the same manner as described above. Such a cycle will be repeated. And, if there is no substrate to be processed, the processing is terminated.

In this way, the final elimination of electric charges stored on the electrostatic chuck can be terminated during the time required for exhausting the processing gas, and consequently it is not required to set a special time required for eliminating electric charges stored on the chuck. This is effective to improve the working ratio of the apparatus.

While in the time chart shown in Fig. 5, the time from stop of supply of a radio frequency voltage to plasma extinction is set at four seconds, it may be suitably set depending on the time required for eliminating a residual attracting force (or eliminating an unbalance between electric charges on both electrodes) after stopping of the plasma. Fig. 6 shows a relationship between a residual attracting force and a time from stop of supply of a radio frequency voltage to plasma extinction. From data shown in Fig. 6, it is revealed that the residual attracting force is not reduced so much in the case where plasma extinction is performed until an elapse of about three seconds since stop of supply of the radio frequency voltage; it is reduced to about a half the original value in the case where plasma extinction is performed after an elapse of about four seconds since stop of supply of the radio frequency voltage; and it is reduced to a low and substantially constant value in the case where plasma extinction is performed after elapse of about five seconds since stop of supply of the radio frequency voltage. The above low residual attracting force after elapse of five seconds is due to the potential differences generated in the case where only the plasma is applied without applying the radio frequency voltage. Accordingly, as described above, there is no problem even when the substrate is removed from the electrostatic chuck in the state that the low residual attracting force remains.

Next, there will be described a manner of removing a substrate from the electrostatic chuck with reference to Figs. 7 and 8. Insulating sleeves 34 are provided in the inner electrode 11 at a plurality of positions. A lift pin 30 for removing the substrate 9 from the mounting surface of the electrostatic chuck is provided in each of the insulating sleeves 34 in such a manner as to pass through the insulating sleeve 34. A stepping motor 32 is mounted on the lower portions of the lift pins 30 through a load cell 31. A signal from the load cell 31 is inputtd into a control unit 33. The control unit 33 outputs a signal for controlling the stepping motor 32. A cover 22 is provided in such a manner as to surround the outer peripheral portion of the electrode 11 and the outer peripheral portion of the substrate 9 in a state in which the substrate 9 is mounted on the insulating film 14 of the electrostatic chuck. Here, a gap between the outer peripheral end surface of the substrate 9 and the cover 22 is within an allowable range of about 1 mm or less. The allowable range of the above gap is set to allow the substrate 9 to be carried to a carrier (not shown) with no problem even when the substrate 9 is offset on the lift pins 30 when removed from the electrostatic chuck using the lift pins 30. With this configuration of the sample stage, even when a residual attracting force remains somewhat, the substrate 9 can be forcibly removed from the electrostatic chuck by the lift pins 30. Specifically, even in the case where the substrate 9 is applied with a force more than the residual attracting force when the lift pins are lifted, and is jumped, the position of the substrate 9 is held by the cover 22. This makes it possible to remove the substrate 9 with a safety even in the case where the

residual attracting force is not perfectly eliminated.

Upon removal of the substrate 9, as shown in Fig. 8, as the lift pins 30 are lifted, the load observed by the load cell 31 is increased at a specific ratio just as the case where a spring load is applied by a component such as bellows. Here, when the lift pins 30 are brought in contact with the back surface of the substrate 9 attracted on the chuck with a residual attracting force, the load cell 31 additionally detects a load due to the residual attracting force. Such an additional load due to the residual attracting force is shown as a locally projecting load appearing in Fig. 8. In this embodiment, to prevent the substrate 9 from being cracked or abnormally jumped due to the residual attracting force when the substrate 9 is forcibly pushed up by the lift pins 30, the push-up force of the lift pins 30 is set at an allowable value. The allowable push-up force is stored in the control unit 33, and the lift pins 30 is lifted by the stepping motor 32 on the basis of the allowable push-up force. Specifically, when the load detected using the load cell 31 exceeds the allowable push-up force by lifting the lift pins 30 after the lift pins 30 are brought in contact with the substrate 9, the control unit 33 operates the stepping motor 32 so as to retard the lifting rate of the lift pins 30 or to stop the lifting of the lift pins 30. This prevents the substrate 9 from being damaged or erroneously carried.

Accordingly, by the above control of removing the substrate 9, it becomes possible to start removal of the substrate 9 after plasma extinction and remove the substrate 9 directly after stop of supply of the DC voltage for electrostatic attraction, and to improve the throughput in carrying the sample.

As described above, according to the bipolar type electrostatic chuck, as the first embodiment, having a gas groove in a sample mounting surface, amounts of electric charges stored on attracting portions corresponding to the positive and negative electrodes directly before stop of supply of a DC voltage for electrostatic attraction are set to be equal to each other, and accordingly, when supply of the DC voltage is stopped, the electric charges equally stored on both the electrodes are eliminated, that is, no electric charges remain on both the electrodes. As a result, it is not required to provide a work of eliminating electric charges stored on the chuck after stop of supply of the DC voltage. This improves the throughput in carrying the sample.

Further, according to the first embodiment, the same insulating film for electrostatic attraction is formed on the inner electrode and the ring electrode, and the areas of attracting portions corresponding to the positive and negative electrodes excluding the gas groove portion are equal to each other, and accordingly, amounts of electric charges stored on attracting portions corresponding to the positive and negative electrodes directly before stop of supply of a DC voltage for electrostatic attraction are set to be equal to each other, so that when supply of the DC voltage is stopped, no electric charges remain on both the electrodes. As a result, it is not required to provide a work of eliminating electric charges stored on the chuck after stop of supply of the DC voltage. This improves the throughput in carrying the sample.

In this way, according to the electrostatic chuck having two electrodes as the first embodiment, since a ratio between areas of wafer attracting portions of the dielectric film positioned on the two electrodes is specified at 1 : 1, a residual attracting force is little generated, with a result that the time required for eliminating the electric charges stored on the chuck can be shortened. Accordingly, in a sample processing apparatus including the electrostatic chuck as the first embodiment, it becomes possible to improve the throughput of the apparatus because the time required for eliminating the electric charges is short, and to prevent the breakage of the wafer upon pushing up the wafer using pushers or the like after termination of processing the wafer because the residual attracting force is little generated.

In the electrostatic chuck as the first embodiment, further, since a pair of the inner electrode and the ring electrode are concentrically disposed, a processing condition is equally applied to the entire substrate in such a manner as to be symmetric around the center of the substrate, so that it is possible to equally process the substrate.

Additionally, in the electrostatic chuck as the first embodiment, the residual attracting force is eliminated after stop of supply of a DC voltage, and accordingly, even after removal of the substrate from the electrostatic chuck, contaminants having electric charges are suppressed from adhering on the substrate mounting surface as compared with the case where there exists the residual attracting force, with a result that there is no fear that contaminants adhere on the back surface of a new substrate.

Although positive and negative voltage having the same potential are applied to the inner electrode 11 and the ring electrode 12 in the first embodiment, the values of the voltages applied from the DC power supplies 81a and 81b to the electrodes 11 and 12 may be varied during plasma processing such that attracting voltages of both the electrodes are equal to each other based on the bias voltage. With this adjustment of the voltages, since electrostatically attracting areas corresponding to both the electrodes are equal to each other, electrostatically attracting forces thereof become equal to each other during plasma processing, with a result that it is possible to prevent the extreme unevenness of a temperature distribution of the sample surface.

With respect to arrangement of a pair of electrodes, the first embodiment has been described by example of the arrangement shown in Fig. 9(a) in which the electrode 12 is disposed slightly inward from the outer peripheral portion of the electrode 11; however, as shown in Fig. 9(b), the electrode 12 may be disposed at the outer peripheral portion of the electrode 11, or it may be disposed at a central portion of the electrode 11.

The arrangement shown in Fig. 9(b) is advantageous in that a recess in which a ring electrode 12a is to be provided can be easily machined, which contributes to reduction in cost. Further, since one end of the ring electrode 12a is in a stress relief state, the ring electrode 12a is not damaged, for example cracked when it undergoes a thermal cycle. According to the arrangement shown in Fig. 9(c), the outer side of an electrode 12b can be easily machined upon formation of a gas groove; and while the plasma processing apparatus is generally difficult in temperature control of the outer peripheral portion, since the outer peripheral portion of the electrode 12b has a high degree of freedom of design for the gas groove, the temperature control for the outer peripheral portion of the electrode 12b can be easily performed.

With respect to connection of DC power supplies to a pair of electrodes, in the first embodiment, the DC power supplies are connected to the electrodes such that a positive potential is applied to the inner electrode 11 and a negative potential is applied to the ring electrode 12; however, there may be adopted a connection manner as shown in Fig. 10. According to the correcting manner shown in Fig. 10, the inner electrode 11 is earthed, and the power supply 8a for electrostatic attraction is connected such that a negative potential is applied to the ring electrode 12. Fig. 11 shows potentials of a wafer and the electrodes when the wafer is electrostatically attracted and held on the chuck shown in Fig. 10 and is exposed to a plasma generated by the plasma generating unit. If a -500 V is applied to the ring electrode 12, the potential of the wafer attracted on the chuck becomes - 250 V and the potential of the inner electrode becomes 0 V. Accordingly, the potential difference (250 V) between the wafer and the ring electrode 12 is equal to the potential difference (250 V) between the wafer and the inner electrode 11. As a result, attracting forces at both the electrode portions are also equal to each other. Then, when the wafer is exposed to the plasma, a bias potential of about -20 V is generated at the wafer, so that the potential difference between the wafer and each electrode is changed. Here, the potential difference between the wafer and the inner electrode 11 is changed from 250 V into 20 V, and the potential difference between the wafer and the ring electrode 12 is changed from 250 V into 480 V. As a result, the attracting force at the inner electrode portion is decreased, while the attracting force at the ring electrode portion is increased. Thus, a cooling gas flowing on the back surface of the wafer is sufficiently sealed in the vicinity of the outer peripheral portion of the wafer, thereby desirably preventing leakage of the heat transfer gas. Further, while in plasma processing, the temperature at the outer portion of the wafer tends to be increased and thereby the outer portion of the wafer must be more strongly cooled, according to this embodiment, the temperature distribution of the wafer during plasma processing can be effectively equalized because the attracting force at the ring electrode 12 portion is increased.

Fig. 12 shows another connection manner in which the power supply 8a for electrostatic attraction is connected with the ring electrode 12 and the inner electrode 11 being made in a floating state with respect to the earth potential, and the ring electrode 12 is applied with a voltage having a potential lower than that of the inner electrode 11. In addition, each electrode can be applied with the same potential by operation of a switch 84a. Fig. 13 shows potentials of a wafer, the ring electrode, and the inner electrode when the wafer is electrostatically attracted and held on the electrostatic chuck in which a potential difference of 500 V is generated between the ring electrode 12 and the inner electrode 11 in accordance with the connection manner shown in Fig. 12. In the electrostatic chuck having such a configuration, the potential of the wafer becomes an intermediate value between potentials of the ring electrode 12 and the inner electrode 11, and the potentials of both the electrodes 11 and 12 become equal to each other. In the case where the wafer is exposed to the plasma in such a state and also a radio frequency voltage is applied to the wafer to generate a bias potential, since the voltages applied to the ring electrode 12 and the inner electrode 11 are in the floating state with respect to the earth potential, both the bias potential and the wafer potential are changed, with a result that the potential difference between the wafer and each electrode is not changed. Accordingly, the amount of the electric charge stored on the actual attracting portion of the dielectric film position on each electrode is not changed, so that the attracting force distribution is also not changed. As a result, there can be obtained an effect in which a residual attracting force is little generated because the attracting force is not changed. Although in the example shown in Fig. 12, the ring electrode 12 is applied with a voltage having a potential lower than that of the inner electrode 11, it may be applied with a voltage having a potential higher than that of the inner electrode 11. Even in this case, there can be obtained the same effect.

Even in the connection shown in Fig. 10, in some cases, a radio frequency voltage is applied to a wafer for generating a bias potential (usually, about -300 V or less) at the wafer thereby promoting processing of the wafer. In this case, potential differences between the wafer and the electrodes are changed, and thereby there occurs a difference between the mounts of the electric charges stored on the electrode portions. To reduce such an unbalance between the amounts of the electric charges stored on the electrode portions (a residual attracting force), as described above, generation of the plasma may be kept for a specific time after stop of supply of the radio frequency voltage, or the DC voltage may be continued to be applied for a specific time after plasma extinction.

In the electrostatic chuck in which the DC power supply is connected as shown in Figs. 10 and 12, by

specifying the amounts of the electric charges stored on the actually attracting portions of the dielectric film positioned on the positive and negative electrodes to be substantially equal to each other the stored electric charges are smoothly eliminated and a residual attracting force is little generated In the case where a very large attracting force is required however a large DC voltage is required to be applied between the positive and negative electrodes In this case the amounts of electric charges stored on the dielectric film are naturally increased so that it takes several or several ten seconds to eliminate the stored electric charges. To short the increased time required for eliminating the stored electric charges. a voltage having a polarity reversed to that applied during electrostatic attraction may be applied between the positive and negative electrodes. Thus. there can be provided the electrostatic chuck and the sample processing apparatus which are capable of shortening a time required for eliminating the stored electric charges.

Next a second embodiment of the present invention will be described with reference to Figs. 14 to 17.

Referring to Fig. 14. there is shown a basic structure of the electrostatic chuck as the second embodiment of the present invention. A dielectric film 35 is fixed on an aluminum block 34 through an adhesive layer 36. The dielectric film 35 is formed of an alumina sintered body. Two electrodes. a ring electrode 31 and an inner electrode 32 are concentrically buried in the dielectric film 35. Each of the two electrodes 31 and 32. made from tungsten. has a thickness of about 50 to 100 μ m. A DC voltage is applied to each of the electrodes 31 and 32 through a lead wire 38 perfectly sealed by an insulating resin layer 43. The lead wire 38 is brazed with each electrode at a portion 37. In this embodiment. an earth voltage is applied to the inner electrode 32. and a DC power supply 40 is connected to the ring electrode 31 through a switch 39 The ring electrode 31 can be connected to the minus potential of the DC power supply 40 or the earth 41 by turning the switch 39. When a negative electrode is applied to the ring electrode 31 by the switch 39 in a state that a wafer is mounted on a surface 44 of the dielectric film 35. a potential difference is generated between the wafer and each electrode. This allows the wafer to be electrostatically attracted and fixed on the contact surface 44. When the ring electrode 31 is earthed by reversely turning the switch 39 an electric charge stored between the wafer and each electrode is eliminated.

While the total thickness of the dielectric film 35 is 1 mm. the thickness of the dielectric film 35 on the electrodes 31 and 32 is 300 μm. The surface roughness of the dielectric film is 3 μm. A gas groove 46 having a depth of about 20 μm is formed in the surface 44 of the dielectric film 35. as shown in Fig. 14. The gas groove 46 is formed in such a shape that a heat transfer gas for promoting cooling of a wafer during processing effectively flows over the entire back surface of the wafer. Into the gas groove 46 is introduced a heat transfer gas from a heat transfer gas inlet 45 through an external pipe (not shown) The gas groove 46 is formed in a pattern capable of giving a desirable temperature distribution to the wafer during processing In this embodiment a ratio between an area of a wafer attracting portion positioned on the ring electrode and an area of a wafer attracting portion positioned on the inner electrode is set at 1 : 1. Also. a ratio between an area of a gas groove portion on the ring electrode and an area of a gas groove portion on the inner electrode is set at 1 : 1 The electrostatic chuck is provided with four lift pins 47 which are concentrically arranged. The lift pin 47 is inserted in an insulating sleeve 48 to be insulated from the electrodes 31 and 32 and the aluminum block 34. The lift pins 47 are vertically driven by a lifting mechanism (not shown) such as an external motor. which are used for carrying a wafer. processing of which has been terminated.

With the electrostatic chuck having the above configuration. the depth of the gas groove is about one-tenth of the thickness of the dielectric film on the electrodes. and thereby the gas groove similarly generates an electrostatically attracting force which is different from those of the actual attracting portions. Figs. 16(a) to 16(c) show a relationship between an electrostatically attracting force and a distance between a wafer and a dielectric film. To examine a wafer attracting force. a spacer was provided on an electrostatic chuck. as shown in Fig. 16 (a). Data are shown in Figs. 16 (b) and 16(c). wherein Fig 16(b) shows the case of using a mirror wafer and Fig 16(c) shows the case of using a wafer with a SiO_2 film From the data shown in Figs. 16(b) and 16(c). it becomes apparent that in each case. an attracting force is little generated when the thickness of the spacer. that is. the distance between the wafer and the dielectric film is more than 30 μm. Accordingly. for a gas groove having the depth smaller than 30 μm. an electrostatically attracting force in the gas groove must be taken into account In particular. since an electrostatically attracting force is certainly generated in a gas groove having the depth smaller than 20 μm. it must be examined.

In this embodiment. since the areas of the actual attracting portions on the inner electrode and the ring electrode are equal to each other and also the areas of the gas groove portions on the inner electrode and the ring electrode are equal to each other. the electric charges stored on the actual attracting portions on the ring electrode and the inner electrode are equal to each other. with a result that a residual attracting force is little generated after stop of supply of the DC voltages as in the first embodiment.

In the electrostatic chuck in the second embodiment. the dielectric film is formed of an alumina sintered body In general. a dielectric film of an electrostatic chuck is made from a ceramic material. The ceramic material. however. has a characteristic in which the resistivity is dependent on an applied voltage and a temperature. as described above Fig. 17 shows a change

in resistivity of the dielectric film used for the electrostatic chuck as the second embodiment depending on the temperature of the dielectric film when a voltage of 200 V is applied thereto From this figure it is revealed that the resistivity of the dielectric film at -50°C is about 30 times that of the dielectric film at 20°C In the case of using a dielectric film having an excessively low resistivity, an electric charge is not stored between the surface of the dielectric film and the back surface of the wafer, and thereby an attracting force is not generated. On the other hand, in the case of using a dielectric film having an excessively high resistivity, a discharge time constant of electric charge stored on the surface of the dielectric film and the back surface of the wafer becomes larger, and thereby a time required for eliminating the stored electric charge is made longer. In this case, a residual attracting force remains.

In a process requiring a fine processing with a good reproducibility, the temperature of an electrostatic chuck is generally controlled for managing the temperature of a wafer during processing. However, since a wafer temperature range is changed depending on the kind of the process, there is a possibility that the electrostatic chuck having a dielectric film largely depending on temperature change cannot be used for a process having a certain wafer temperature range. For example, in an etching apparatus, a wafer temperature is required to be controlled in a range of a low temperature, about -60°C to about 100°C. In a film formation apparatus using CVD or sputtering, a wafer temperature is in a range of 100°C to a high temperature, about 700°C. In this case, the resistivity of a dielectric film is adjusted by addition of an impurity such as a metal oxide in a basic material of the dielectric film in order that it becomes a suitable value in a service temperature range.

An electrostatic chuck having the dielectric film thus adjusted is allowed to quickly eliminate the electric charges on the chuck while ensuring a sufficient attracting force in the entire range of service temperatures. Also, a sample processing apparatus using such an electrostatic chuck is allowed to improve a working ratio because only one of the apparatus can carry out processes in a wide temperature range.

Additionally, in the case of using the electrostatic chuck for processes having different service temperature ranges, the attracting force differs between the service temperature ranges of the processes because the resistivity of the dielectric film is dependent on the temperature. The changed attracting force varies a thermal conductivity of an attracting portion, which possibly results in a change in process. To cope with such an inconvenience, an applied voltage is changed to generate a constant attracting force in a service temperature range on the basis of the previously examined data on a change in resistivity of the dielectric film in the service temperature range

A sample processing apparatus including the electrostatic chuck having the above configuration is allowed to usually process wafers with a good producibility.

In the above-described first and second embodiments, actual attracting areas corresponding to positive and negative electrodes are set to be equal to each other for making equal to each other, amounts of positive and negative electric charges stored on an electrostatically attracting film (insulating film 14, dielectric film 35) directly before stop of supply of DC voltages for electrostatic attraction. In some cases, however the above attracting areas cannot set to be equal to each other. In these cases, there may be adopted the following manner:

For example, assuming that in Fig. 14, the area of the actual attracting portion on the inner electrode 32 is taken as 54 cm^2 and the area of the actual attracting portion on the ring electrode 31 is taken as 152.5 cm^2, the area of the actual attracting portion on the ring electrode 31 side is 2.8 times the area of the actual attracting portion on the inner electrode 32 side. Accordingly, in order that amounts of electric charges stored between the attracted wafer and the dielectric film on the electrodes 31 and 32 are substantially equal to each other when a service voltage of 400 V is applied, the surface roughness of the dielectric film on the inner electrode 32 is set at 3 μm and the surface roughness of the dielectric film on the ring electrode 31 is set at 3.9 μm on the basis of the principle having been described with reference to Figs. 22 to 25. Here, potentials generated between the wafer and the electrodes 32 and 31, and electrostatic capacities of the dielectric film on the electrodes 32 and 31 are calculated, on the basis of the above-described equations, as follows: namely, the potential between the wafer and the inner electrode 32 is 274 V and the potential between the wafer and the ring electrode 31 is 126 V, and the electrostatic capacity of the dielectric film on the inner electrode 32 is 16 nF and the electrostatic capacity of the dielectric film on the ring electrode 31 is 35 nF. On the basis of these conditions, amounts of electric charges stored on the dielectric film on the electrodes 32 and 31 are calculated as follows: namely, the amount of the electric charge stored on the dielectric film on the inner electrode 32 is 4.4×10^{-6} coulomb, and the amount of the electric charge stored on the dielectric film on the ring electrode 31 is 4.4×10^{-6} coulomb. This result shows that the amounts of the electric charges stored on the dielectric film on the electrodes 32 and 31 are substantially equal to each other. Accordingly, when supply of the DC voltages is stopped in such a state, generation of a residual attracting force is suppressed on the basis of the principle having been described with reference to Figs. 22 to 25, with a result that a time required for eliminating the stored electric charges is shortened.

Specifically, when an electrostatic chuck is designed such that the product of a ratio between electrostatic capacities of actual attracting portions of a dielectric film on respective electrodes and a ratio between

resistances of the actual attracting portions of the dielectric film on the electrodes is set at approximately 1 that is the relationship of Ca × Ra = Cb × Rb obtained from the relationship of Ca × Va = Cb × Vb is satisfied the amounts of the electric charges stored on the actual attracting portions of the dielectric film on the electrodes during attraction of the wafer are equal to each other The electrostatic chuck thus designed makes it possible to suppress generation of a residual attracting force

In the above description the attracting area on the inner electrode 32 side is made small however in some processing conditions the attracting area on the ring electrode 31 side may be made smaller. As a result of an experimental examination of a relationship between an electrostatically attracting force and a wafer temperature when a gas is supplied to the back surface of the wafer it was found that the wafer is more effectively cooled as the electrostatically attracting force becomes larger. On the other hand when electrostatic capacities (Q = C × V) at respective electrode portions are equal to each other the attracting force per unit area becomes larger as the electrostatically attracting area becomes smaller. On the basis of the data in the case where the outer portion of a sample is required to be more strongly cooled or heated in consideration of a temperature distribution within a sample surface upon processing the sample the temperature distribution can be improved by supplying a cooling gas on the back surface of the sample and strongly attracting and holding the outer portion of the sample. Accordingly in the case where attracting areas are different by suitably setting the attracting areas on respective electrodes the temperature distribution within the sample surface can be adjusted

Next a third embodiment of the electrostatic chuck of the present invention will be described with reference to Fig 18. In this embodiment a new dummy wafer 50 is placed on a dielectric film 53 and is attracted by applying a voltage which is larger than a voltage applied in the actual processing by a DC power supply 54 As a result contaminants adhering on the surface of the dielectric film for example contaminants having a negative electric charge and not allowed to be usually made repulsive by an negative electric charge generated during usual attraction of a wafer are made repulsive by a negative electric charge larger than that generated during usual attraction of the wafer and are transferred on the back surface of the wafer The dummy wafer is then removed from the chuck in the same manner as that used for usual carrying of the wafer Thus the contaminants adhering on the dielectric film can be removed. Although in this figure only the contaminants having a negative electric charge are shown; however actually contaminants having a positive electric charge adhere on the surface of the dielectric film.

In the electrostatic chuck in which the above work is periodically repeated it is possible to reduce the number of contaminants adhering on the back surface of a wafer to be processed and to usually subject wafers to a clean process Accordingly a processing apparatus including the electrostatic chuck in this embodiment is allowed to improve the yield of products In addition since the number of disassembling works for cleaning contaminants stored in the apparatus can be reduced the working ratio of the apparatus can be enhanced

Although the manner of removing contaminants having a positive or negative electric charge has been described in the third embodiment a manner of removing contaminants having positive and negative electric charges will be described with reference to Fig. 19. In this case the DC power supply shown in Fig 18 is replaced with a DC power supply capable of suitably switching the polarity (positive or negative) of an applied voltage. A new dummy wafer 50 is placed on the surface of the dielectric film 53 and a DC voltage having an absolute value larger than that of a voltage applied for usual attraction of a wafer is applied in such a manner as to be alternately changed in polarity as shown in Fig. 19. With this operation contaminants not allowed to be removed by the operation shown in Fig. 18 that is contaminants having a positive electric charge and electrostatically attracted on the dielectric film can be transferred on the dummy wafer to be thus removed from the chuck. According to this embodiment therefore the dielectric film can be effectively cleaned.

In this embodiment a new dummy wafer is used for removing contaminants on the dielectric film; however it may be replaced with any member made from a conductive or semiconducting material in a clean state. However it is desired to avoid a member containing a material causing a heavy metal contamination

In addition although a DC voltage is applied in such a manner as to be alternately changed in polarity in this embodiment the present invention is not limited thereto and for example the same effect can be obtained by applying an AC voltage

A fourth embodiment using the electrostatic chuck of the present invention will be described with reference to Figs. 20 and 21. Fig. 20 shows the configuration of a sample processing apparatus using the electrostatic chuck of the present invention. The sample processing apparatus is composed of an atmospheric loader unit and a vacuum processing unit. The atmospheric loader unit has cassette mounting areas on which a plurality of cassettes 61 can be mounted. The atmospheric loader unit also has an atmospheric carrying robot 62 for carrying wafers contained in each cassette 61 into the vacuum processing unit or returning the wafers having been processed in the vacuum processing unit into the cassette 61 The vacuum processing unit has a load lock chamber 63 unload lock chamber 64 and processing chambers A B C and D which are indicated by reference numerals 70 71 72 and 73 These chambers are arranged around a vacuum carrying chamber 65 and are connected thereto The load lock chamber 63 and the unload lock chamber 64 are positioned on the atmospheric loader 60 side A vacuum carrying robot 66

is provided in the vacuum carrying chamber 65. The vacuum carrying robot 66 includes an arm 67. The leading end of the arm 67 has a hand 68. The vacuum carrying robot 66 is actuated in such a manner that the hand 69 is allowed to be inserted in each of the chambers 63, 64, 70, 71, 72 and 73. The hand 68 has wafer mounting surfaces disposed on both the ends. The wafer mounting surface disposed at the leading end of the hand 68 is formed with an electrostatic chuck shown in Fig. 21. The electrostatic chuck is composed of an outer electrode 681, an insulating film 682, an inner electrode 683, and an insulating film 684 for electrostatic attraction. The outer electrode 681 disposed at the leading end of the hand 68 has, for example, three projections. A recess is formed in part of each projection, and the inner electrode 683 is provided in the recess. An insulating sleeve 685 is mounted in the recess of the outer electrode 681 in such a manner as to pass through the outer electrode 681, and an electrode core 686 is provided in the insulating sleeve 685. An insulating film 682 is formed on the surface of the recess by thermal spraying, and the inner electrode 683 is formed on the insulating film 682 by thermal spraying. The inner electrode 683 can be easily connected to the electrode core 686 by thermal spraying of the inner electrode 683. On the top surfaces of the outer electrode 681 and the inner electrode 683, is formed an insulating film 684 by thermal spraying. A lead wire 689 is connected to the electrode core 686, and a lead wire 688 is connected to the outer electrode 681. The lead wires 688 and 689 are connected to a power supply for electrostatic attraction (not shown). An insulating cover 687 is provided on the bottom surface of the outer electrode 681. Here, in order to suppress adhesion of contaminants, a wafer contact surface of an electrostatically attracting portion formed on the projection is made as small as possible. Further, the areas of electrostatically attracting surfaces corresponding to the outer electrode 681 and the inner electrode 683 are equal to each other.

With the sample processing apparatus having the above configuration, a wafer is taken out of the cassette 61 and is carried into the load lock chamber 63 by the atmospheric robot 62. The wafer thus transferred into the load lock chamber 63 is then carried into a designated processing chamber (for example, processing chamber 71) by the vacuum carrying robot 66. At this time, the hand 68 receives at the one end the wafer having been processed in the processing chamber 71, being turned, and carries a non-processed wafer into the processing chamber 71. The already processed wafer held by the one end of the hand 68 is carried into the next processing chamber (for example, processing chamber 70) by the vacuum carrying robot 66. On the other hand, the wafer to be processed in a different processing chamber (for example, processing chamber 72) is carried by the similar operation of the atmospheric carrying robot 62 and the vacuum carrying robot 69.

Here, when the vacuum carrying robot 66 receives the wafer from the load lock chamber 63 or each processing chamber, positive and negative DC voltages having the same potential are applied to the outer electrode 681 and the inner electrode 683, so that amounts of electric charges stored on the electrostatically attracting surfaces of the insulating film positioned on the electrodes 681 and 683 are equal to each other. When the vacuum carrying robot 66 delivers the wafer into the unload lock chamber 64 or each processing chamber, supply of the DC voltages applied to the outer electrode 681 and the inner electrode 683 is stopped, so that the electric charges stored on the electrostatically attracting surfaces of the insulating film positioned on the electrodes 681 and 683 are balancedly eliminated. As a result, residual attracting forces do not remain on the electrostatically attracting surfaces. Thus, the wafer is easily removed from the electrostatically attracting surfaces. The removal of the wafer from the electrostatically attracting surfaces of the hand 68 is performed using lift pins as shown in Figs. 7 and 8. In removal of the wafer from the hand 68, supply of the DC voltages for electrostatic attraction is stopped when the wafer on the hand 68 is arrived at a specified position and stopped by the vacuum carrying robot 66. At the same time, the lifting of the lift pins is started when the wafer is arrived at the specific position and is stopped. Even when the electric charges stored on the electrostatic chuck are not perfectly eliminated at the time when the lift pins are brought in contact with the wafer, the wafer is not damaged because as shown in Figs. 7 and 8, the push-up force of the lift pins is adjusted by controlling the action of a stepping motor while detecting the push-up force of the lift pins using a load cell. As a result, the wafer can be removed without lifting the lift pins after an elapse of several seconds (about two or three seconds) until the electric charges polarized on the positive and negative electrodes are eliminated after stop of supply of the DC voltages, to thereby improve the throughput in carrying the wafer. In addition, if the period of time, several seconds, until the electric charges are eliminated does not affect the entire throughput of wafer processing, it is not required to control the push-up force of the lift pins using the load cell.

Further, since the amounts of the electric charges stored on the electrostatically attracting surfaces of the insulating film are equal to each other directly before stop of supply of the DC voltages, the residual attracting force can be certainly eliminated only by stopping application of the DC voltages for electrostatic attraction. Accordingly, even in the case of using the electrostatic chuck as the wafer holding portion of the atmospheric carrying robot 62, it can transfer a wafer on a containing stage in a cassette without no problem.

As described above, according to the sample processing apparatus in this embodiment, since a wafer can be certainly held on the arm by use of the electrostatic chuck of the present invention as the wafer holding portion of the carrying robot, reliability in carrying wafers

can be improved.

Also, since a wafer can be certainly held on the arm, the carrying speed of the carrying robot can be increased, to thereby improve the throughput. Further, in the case where the electrostatic chuck of the present invention is used for the carrying robot provided with the hand having two wafer holding portions on the arm, when a wafer having been processed in a processing chamber is exchanged with a non-processed wafer, the wafer is not removed by a centrifugal force even by increasing a turning speed when the wafer is turned from one end to the other end of the hand, that is, the arm (or the hand) is rotated by the carrying robot. Accordingly, exchange of wafers in processing chambers can be quickly performed, thereby reducing a loss time in wafer processing.

In addition, the atmospheric carrying robot uses the electrostatic chuck in this embodiment; however, it may adopts a different holding means such as a vacuum chuck.

Although the electrostatic chuck, and the method of and apparatus for processing a sample using the electrostatic chuck according to the present invention have been described by example of the first, second, third and fourth embodiments, the most important point of the present invention lies in that in the electrostatic chuck applied to a sample processing apparatus or a sample carrying apparatus, amounts of electric charges stored on a dielectric film directly before stop of supply of a DC voltage applied between positive and negative electrodes are equal to each other. The electrostatic chuck having such a configuration is allowed to smoothly eliminate the stored electric charges and to substantially prevent generation of a residual attracting force. Next, in the sample processing apparatus, represented by a plasma processing apparatus or a vacuum processing apparatus, using the electrostatic chuck, a sample can be certainly held during processing or carrying the wafer, or upon deliver of the wafer to the next processing chamber, the wafer can be quickly removed from the chuck without damage of the wafer, so that it is possible to improve the working ratio of the apparatus.

As described above, according to the electrostatic chuck of the present invention, since amounts of electric charges stored on electrostatically attracting surfaces of an insulating film corresponding to positive and negative electrodes directly before stop of supply of DC voltages applied to the electrodes are equal to each other, the electric charges stored on the electrostatically attracting surfaces of the insulating film can be quickly eliminated without separately providing any electric charge eliminating step after stop of supply of the DC voltages, so that a residual attracting force is little generated and a time required for eliminating the stored electric charges is shortened.

According to the sample processing apparatus using the electrostatic chuck of the present invention, since a residual attracting force is little generated and a time required for eliminating the stored electric charges is shortened, lowering of a processing ability of the processing apparatus can be prevented. In addition, according to the electrostatic chuck of the present invention, it takes two or three seconds to eliminate the stored electric charges. Such a time is not regarded as a loss time in consideration of a time required for operating lift pins or the like. However, if needed, the electric charges stored on the dielectric film can be more quickly eliminated by applying voltages having polarities reversed to those of the voltages for electrostatic attraction after stop of the applied voltages.

In particular, according to the plasma processing apparatus using the electrostatic chuck of the present invention, it is possible to eliminate an unbalance between amounts of electric charges generated during plasma processing which is performed simultaneously with application of a radio frequency voltage for generating a bias voltage, by keeping generation of the plasma for a specific time after stop of application of the radio frequency voltage. Also, it is possible to eliminate an unbalance between amounts of electric charges generated during plasma processing by applying the DC voltages for electrostatic attraction for a specific time after plasma extinction. Further, since elimination of electric charges stored on the electrostatically attracting insulating film after stop of supply of the DC voltages for electrostatic attraction is performed within a processing gas exhausting time, it is possible to prevent lowering of a processing ability due to the electrostatic chuck.

According to the electrostatic chuck of the present invention, particularly, since a residual attracting force is eliminated after stop of supply of the DC voltages, a substrate mounting surface is suppressed from being stuck with contaminants having an electric charge as compared with a chuck in which there exists a residual attracting force, so that the back surface of a new substrate is prevented from being stuck with contaminants.

In the case where contaminants adhere on the electrostatic chuck of the present invention, the contaminants, which adhere on a dielectric film (insulating film for electrostatic attraction) of the chuck, can be transferred on a dummy wafer to be thus removed by applying a voltage higher than the usual applied voltage between the electrodes for electrostatic attraction or by applying an AC voltage having an absolute value larger than that of the usual applied voltage between the electrodes. Thus, by periodically repeating the above operation, it is possible to reduce contaminants adhering on the back surface of a product wafer.

Additionally, in the case where the electrostatic chucks of the present invention are used for all of wafer holding portions of a sample processing apparatus, since a residual attracting force is little generated at each of the wafer holding portions, it is possible to certainly deliver a wafer because the wafer is easily removed from the wafer holding portion, and hence to significantly enhance the reliability of the apparatus.

Additionally, in the case where there occurs power failure during processing of a wafer held by an electrostatic chuck, the attracting force of the wafer is reduced and it is floated and offset by a pressure of a heat transfer gas remaining on the back surface of the wafer. In this case, the pressure of the heat transfer gas may be reduced during the attracting force of the wafer is kept. Specifically, when the supply of the DC voltages to the electrostatic chuck is abruptly stopped, the attracting force is kept for a specific period of time by auxiliary batteries attached to the DC power supplies for supplying voltages to the inner electrode and ring electrode, and during the specific period of time, the heat transfer gas may be exhausted. One of the simple methods for exhausting a heat transfer gas is to provide a valve for opening a supply line of the heat transfer gas in the supply line, thereby connecting the supply line communicated to the back surface of the wafer into a processing chamber in which the wafer is disposed when the supply of the voltage is stopped. According to this method, when the supply of the voltages is stopped, the heat transfer gas flows in the processing chamber, and the pressure at the back surface is balanced against the pressure of the processing chamber, to thereby prevent the wafer from being offset.

Claims

1. An electrostatic chuck comprising:

   a pair of electrodes having different polarities; and
   a dielectric film, formed on top surfaces of said pair of electrodes, on which a sample is electrostatically attracted and held when a DC voltage is applied between said pair of electrodes;
   wherein amounts of electric charges stored on attracting portions of said dielectric film corresponding to said pair of electrodes directly before stop of supply of the DC voltage applied between said pair of electrodes are substantially equal to each other.

2. An electrostatic chuck comprising:

   a pair of electrodes having different polarities; and
   a dielectric film, formed on top surfaces of said pair of electrodes, on which a sample is electrostatically attracted and held when a DC voltage is applied between said pair of electrodes;
   wherein part of said dielectric film on said pair of electrodes has projecting portions corresponding to said pair of electrodes, and attracting portions corresponding to said pair of electrodes are formed of said projecting portions; and
   areas of said attracting portions of said dielectric film corresponding to said pair of electrodes are substantially equal to each other.

3. An electrostatic chuck comprising:

   a pair of electrodes having different polarities; and
   a dielectric film, formed on top surfaces of said pair of electrodes, on which a sample is electrostatically attracted and held when a DC voltage is applied between said pair of electrodes;
   wherein the product of a ratio between electrostatic capacities between said positive and negative electrodes and said wafer and a ratio between resistances of portions of said dielectric film on said positive and negative electrodes is specified to be approximately 1, by changing areas and surface roughnesses of actual attracting portions of said dielectric film corresponding to said positive and negative electrodes.

4. An electrostatic chuck used for a vacuum processing apparatus adapted to process a sample while controlling the temperature of said sample by supplying a heat transfer gas on the back surface of said sample, said electrostatic chuck comprising:

   a gas groove provided in a sample mounting surface of said chuck;
   a dielectric film, formed on said sample mounting surface, on which said sample is electrostatically attracted and held; and
   positive and negative electrodes disposed on the underside of said dielectric film;
   wherein amounts of electric charges stored on portions of said dielectric film corresponding to said positive and negative electrodes are substantially equal to each other.

5. An electrostatic chuck used for a vacuum processing apparatus adapted to process a sample while controlling the temperature of said sample by supplying a heat transfer gas on the back surface of said sample, said electrostatic chuck comprising:

   a gas groove provided in a sample mounting surface of said chuck;
   a dielectric film, formed on said sample mounting surface, on which said sample is electrostatically attracted and held; and
   positive and negative electrodes disposed on the underside of said dielectric film;
   wherein areas of actual sample contact surfaces composed of projecting portions corresponding to said positive and negative electrodes excluding said gas groove are substan-

tially equal to each other

6. An electrostatic chuck used for a vacuum processing apparatus using a plasma comprising

   a groove or a recess provided in a sample mounting surface of said chuck.
   a dielectric film formed on said sample mounting surface on which said sample is electrostatically attracted and held and
   positive and negative electrodes disposed on the underside of said dielectric film
   wherein amounts of electric charges stored on said dielectric film corresponding to said positive and negative electrodes directly before stop of supply of a DC voltage between said positive and negative electrodes after plasma extinction are substantially equal to each other.

7. An electrostatic chuck used for a vacuum processing apparatus using a plasma. comprising:

   a groove or a recess provided in a sample mounting surface of said chuck:
   a dielectric film. formed on said sample mounting surface. on which said sample is electrostatically attracted and held. and
   positive and negative electrodes disposed on the underside of said dielectric film.
   wherein areas of actual sample contact surfaces composed of projecting portions corresponding to said positive and negative electrodes excluding said groove or recess. are substantially equal to each other

8. A sample processing method comprising the steps of

   electrostatically attracting and holding a sample on an electrostatic chuck including a pair of electrodes having different polarities and a dielectric film formed on top surfaces of said pair of electrodes. by applying a DC voltage between said pair of electrodes and
   processing said sample electrostatically attracted and held on said chuck through said dielectric film:
   wherein amounts of electric charges stored on attracting portions of said dielectric film corresponding to said pair of electrodes directly before stop of supply of the DC voltage applied between said pair of electrodes after termination of processing said sample are substantially equal to each other. so that the electric charges stored on said attracting portions of said dielectric film after stop of supply of the DC voltage are eliminated due to the balance therebetween. whereby said sample is removed from the sample mounting surface without addition of any special step

9. A sample processing method according to claim 8 wherein said processing of said sample is plasma processing and said method further comprises a step of applying a radio frequency voltage for generating a bias voltage in said plasma processing. and a step of keeping generation of the plasma for a specific time after stop of application of said radio frequency voltage upon termination of processing said sample

10. A sample processing method according to claim 9. further comprising the step of keeping application of the DC voltage between said electrodes for a specific time after plasma extinction

11. A sample processing apparatus for processing a sample electrostatically attracted and held on an electrostatic chuck. said electrostatic chuck comprising:

    an electrostatic chuck including a pair of electrodes having different polarities and a dielectric film. formed on top surfaces of said pair of electrodes. on which a sample is electrostatically attracted and held when a DC voltage is applied between said pair of electrodes
    wherein a recess being not in contact with the back surface of said sample is formed in a surface of said dielectric film on which said sample is disposed: and
    amounts of electric charges of different polarities stored on attracting portions of the surface of said dielectric film excluding said recess are equal to each other.

12. A sample processing apparatus according to claim 11 wherein areas of attracting surfaces of said attracting portions of the surface of said dielectric film on which electric charges of different polarities are stored are substantially equal to each other

13. A sample processing apparatus according to claim 11. wherein the product of a ratio between electrostatic capacities between said electrodes having different polarities and said wafer and a ratio between resistances of portions of said dielectric film on said electrodes having different polarities is specified to be approximately 1. by changing areas and surface roughnesses of said attracting portions of the surface of said dielectric film on said electrodes having different polarities.

14. A sample processing apparatus according to claim 11. further comprising a means for keeping application of the DC voltage between said electrodes for

a specific time after plasma extinction

15. A sample processing apparatus according to claim 12. further comprising a means for removing said sample from said sample mounting surface without addition of any other step after stop of supply of the DC voltage between said electrodes

16. A sample processing apparatus according to claim 11. wherein said processing of said sample is plasma processing. and said apparatus comprises a means for applying a radio frequency voltage for generating a bias voltage during said plasma processing. and a means for keeping generation of the plasma for a specific time after stop of supply of said radio frequency voltage upon termination of processing said wafer.

17. A sample processing apparatus according to claim 16, further comprising a means for keeping application of the DC voltage between said electrodes for a specific time after plasma extinction.

18. A sample processing method. comprising the steps of:

electrostatically attracting and holding a sample on an electrostatic chuck including a pair of electrodes having different polarities and concentrically disposed. and a dielectric film formed on top surfaces of said pair of electrodes, by applying a DC voltage between said pair of electrodes:
subjecting said sample attracted and held on said chuck through said dielectric film to plasma processing while applying a bias voltage:
stopping application of the bias voltage applied during plasma processing after termination of processing said sample:
continuing generation of the plasma for a specific time after stop of supply of the bias voltage. and extinguishing the plasma after an elapse of said specific time:
keeping application of the DC voltage between aid electrodes for a specific time after plasma extinction: and
stopping application of the DC voltage between said electrodes. and lifting lift pins while controlling a push-up force of said lift pins applied to said sample in an allowable range. thereby removing said sample from said chuck.

19. A sample processing apparatus comprising:

a vacuum processing chamber in which a plasma is generated:
a sample stage. provided in said vacuum processing chamber. on which a sample to be subjected to plasma processing is amounted.
a radio frequency power supply. connected to said sample stage. for applying a bias voltage to said sample stage. and
an electrostatic chuck. provided on said sample state. said chuck comprising:
a conductor electrically insulated from said sample stage. said conductor passing through said sample stage and being exposed on a sample mounting surface side of said sample stage:
an insulating film composed of a thermal spray film partially provided on the sample mounting surface side of said sample stage in such a manner as to surround said conductor: and
electrodes composed of a thermal spray film partially formed in such a manner as to be connected to said conductor. said electrodes being provided on the sample mounting surface side of said sample stage through said insulating film.
wherein said electrodes composed of the thermal spray film and the surface of said sample stage on the sample mounting surface side excluding said electrodes composed of the thermal spray film are covered with an electrically insulating film composed of a thermal spray film.

20. A sample processing apparatus according to claim 19. wherein said conductor passing through said sample stage is fixed on said sample stage. and a socket portion is formed in said conductor on the side reversed to said electrodes and a wiring terminal of a power supply for electrostatic attraction is connected to said socket portion.

FIG. 1

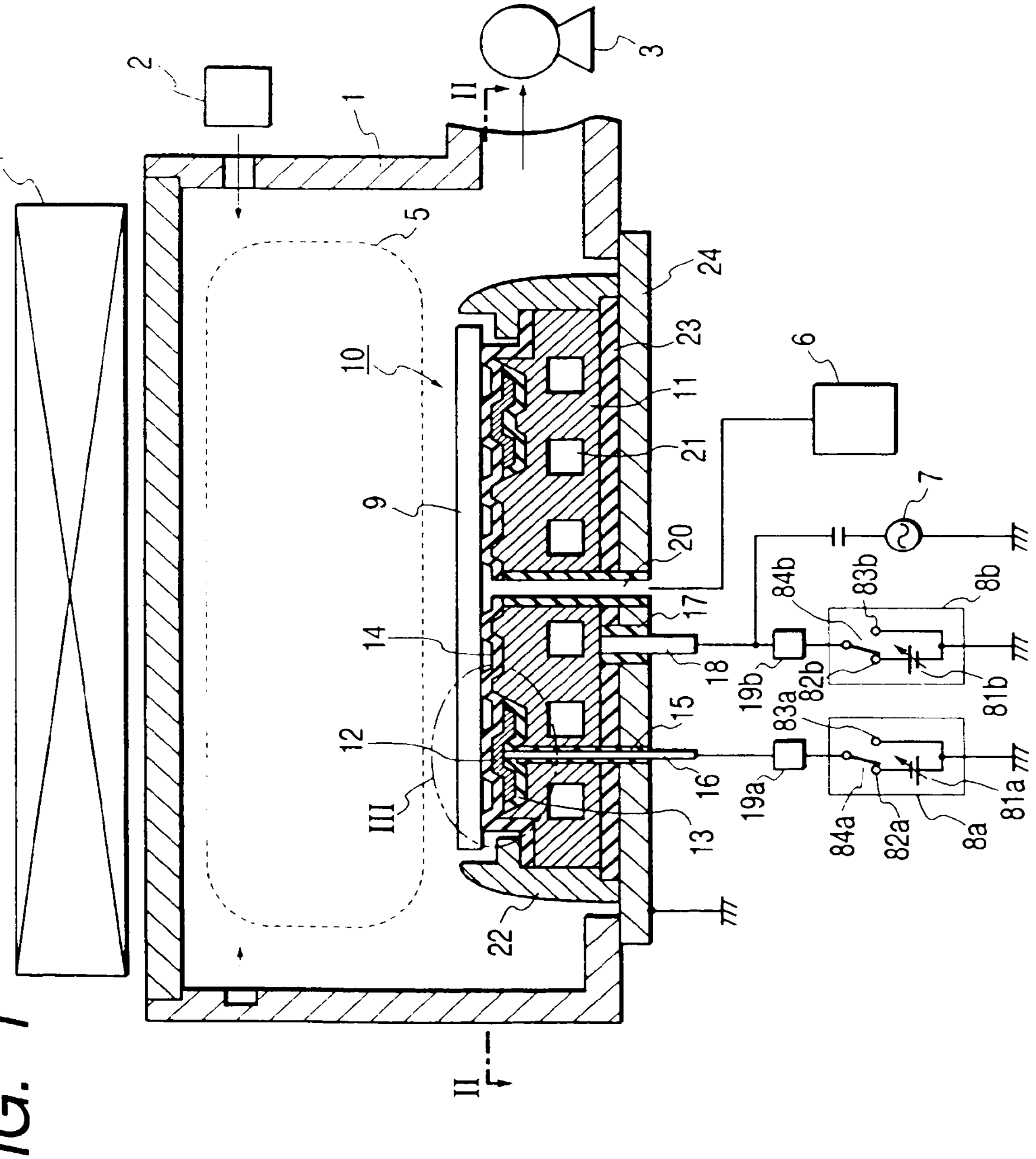

1
2
3
4
5
6
7
8a
8b
9
10
11
12
13
14
15
16
17
18
19a
19b
20
21
22
23
24
81a
81b
82a
82b
83a
83b
84a
84b
II
III

FIG. 2

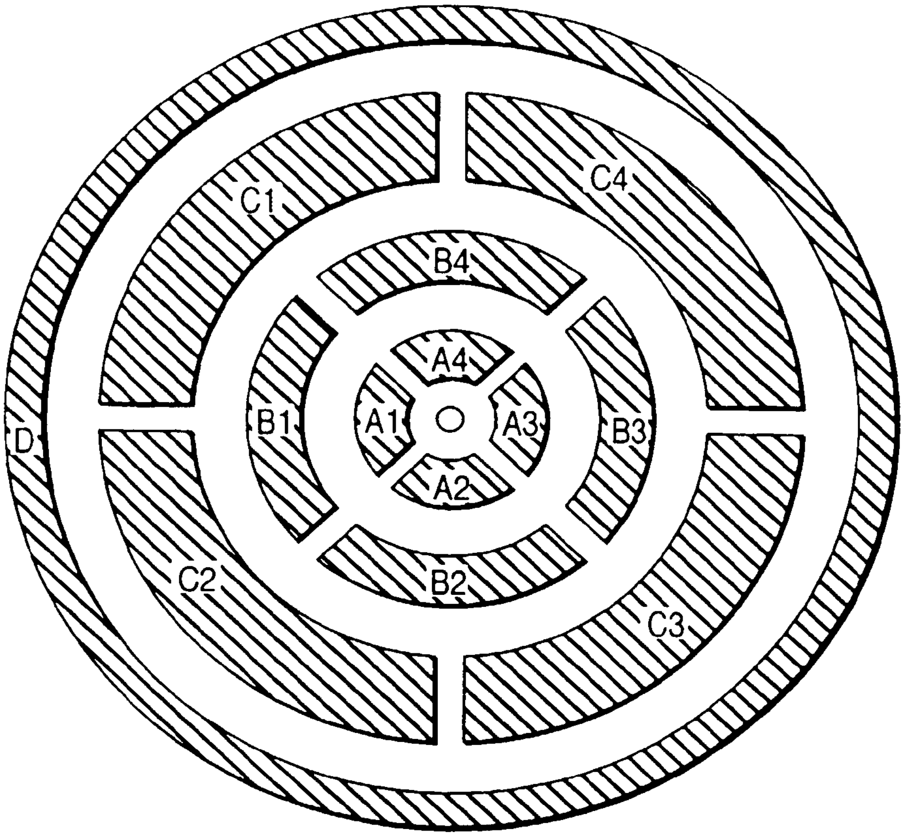


FIG. 3

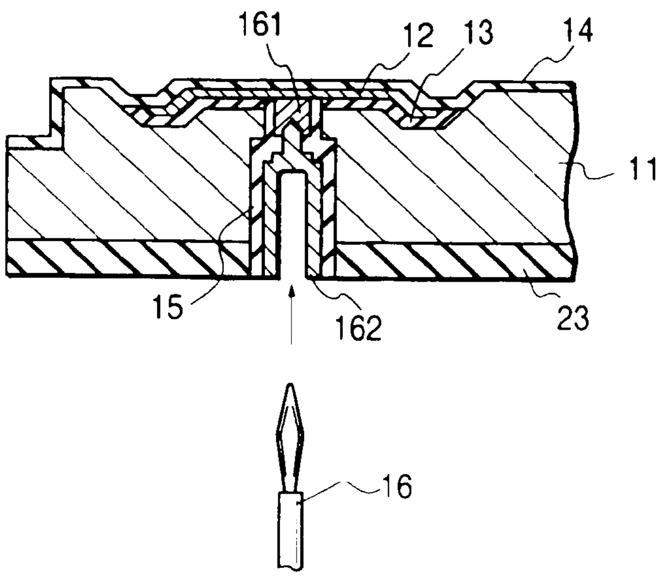


FIG. 4

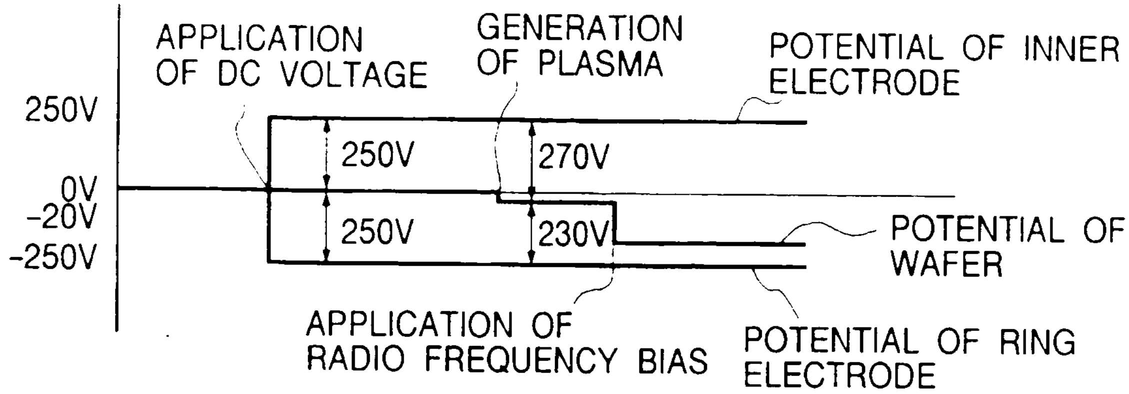

APPLICATION
OF DC VOLTAGE
GENERATION
OF PLASMA
POTENTIAL OF INNER
ELECTRODE
250V
0V
-20V
-250V
250V
270V
250V
230V
POTENTIAL OF
WAFER
APPLICATION OF
RADIO FREQUENCY BIAS
POTENTIAL OF RING
ELECTRODE

FIG. 5

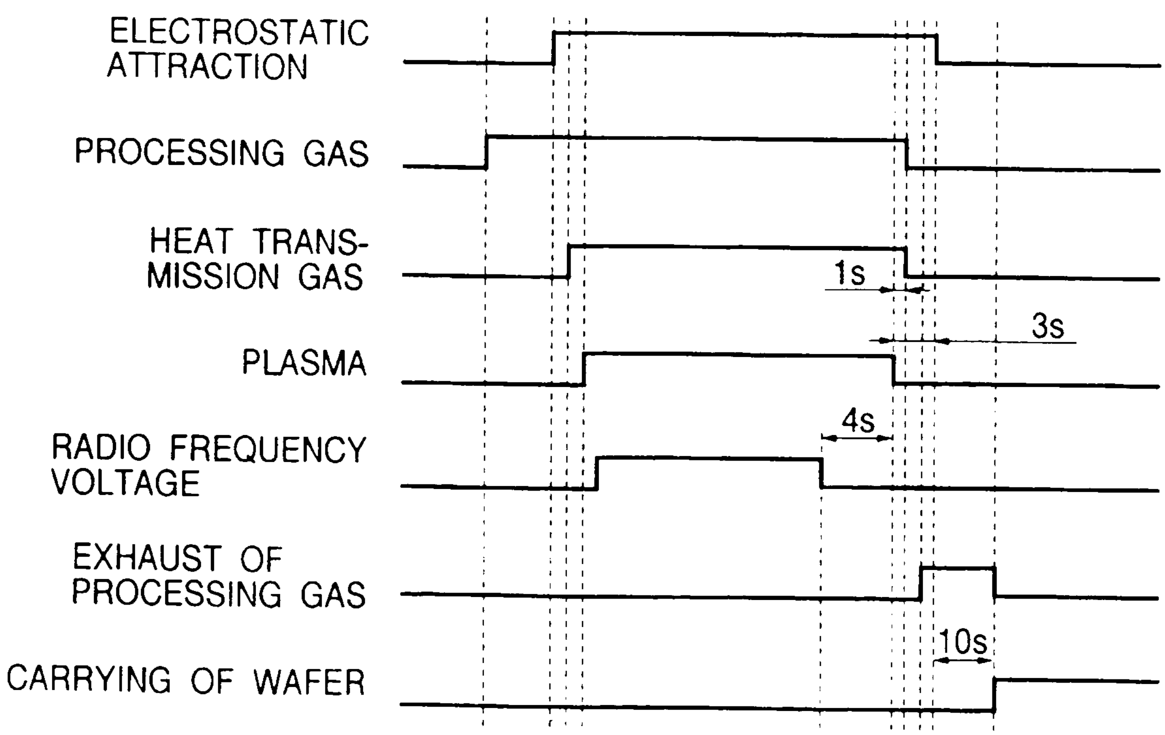

ELECTROSTATIC
ATTRACTION
PROCESSING GAS
HEAT TRANS-
MISSION GAS
1s
3s
PLASMA
4s
RADIO FREQUENCY
VOLTAGE
EXHAUST OF
PROCESSING GAS
10s
CARRYING OF WAFER

FIG. 6

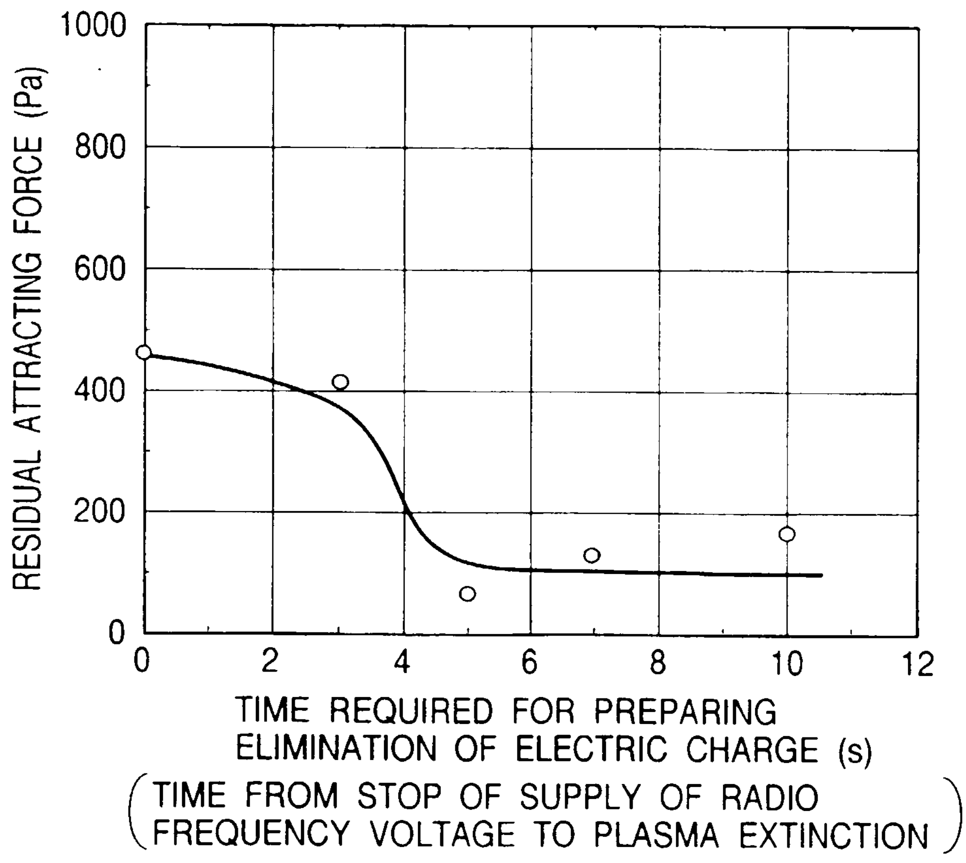

RESIDUAL ATTRACTING FORCE (Pa)
1000
800
600
400
200
0
0
2
4
6
8
10
12
TIME REQUIRED FOR PREPARING ELIMINATION OF ELECTRIC CHARGE (s)
(TIME FROM STOP OF SUPPLY OF RADIO FREQUENCY VOLTAGE TO PLASMA EXTINCTION)

FIG. 7

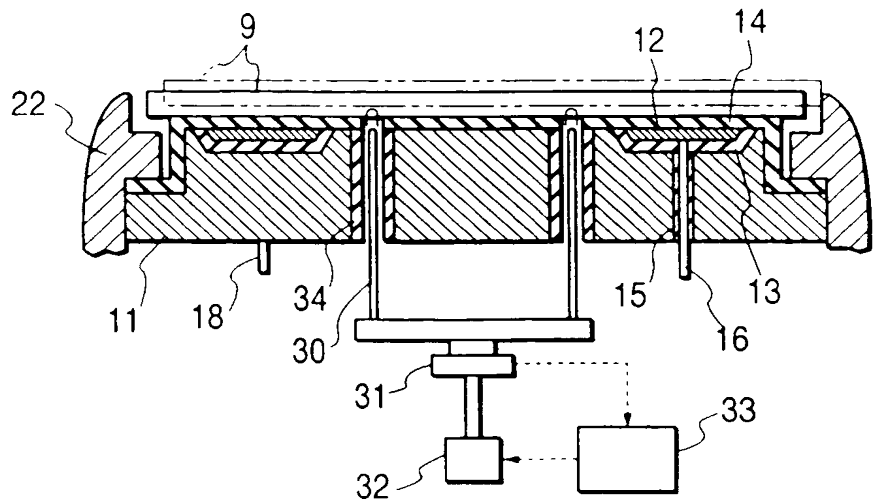

9
12
14
22
11
18
34
30
15
13
16
31
33
32

FIG. 8

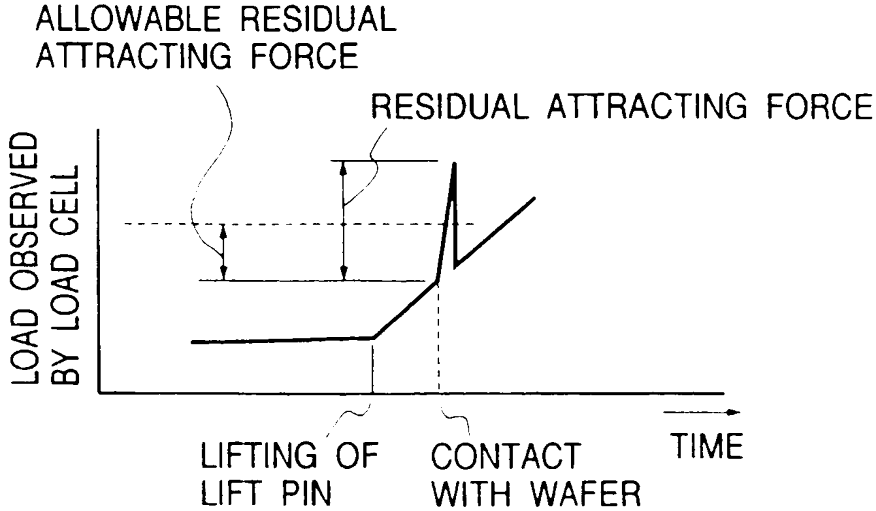

ALLOWABLE RESIDUAL ATTRACTING FORCE
RESIDUAL ATTRACTING FORCE
LOAD OBSERVED BY LOAD CELL
LIFTING OF LIFT PIN
CONTACT WITH WAFER
TIME

FIG. 9(a)

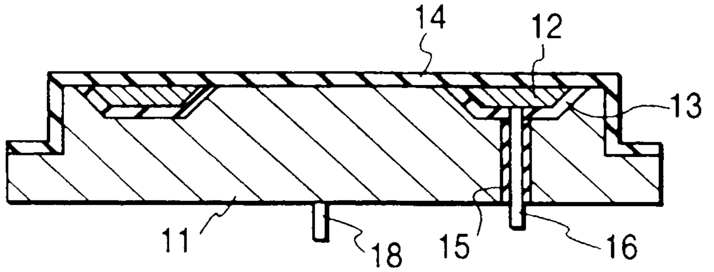


FIG. 9(b)

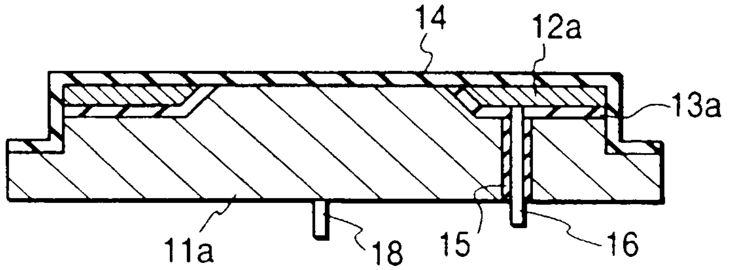


FIG. 9(c)

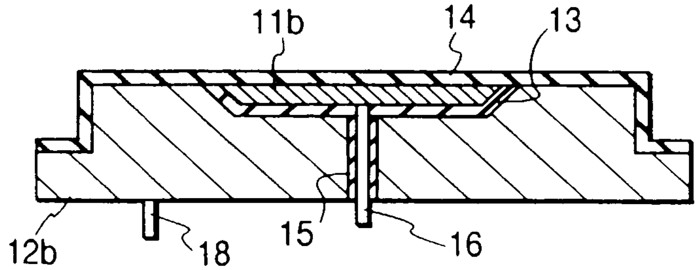


FIG. 10

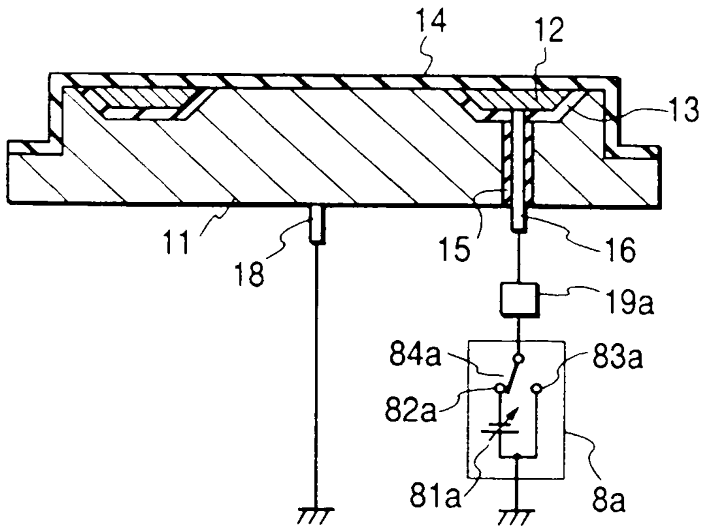

14
12
13
11
18
15
16
19a
84a
83a
82a
81a
8a

FIG. 11

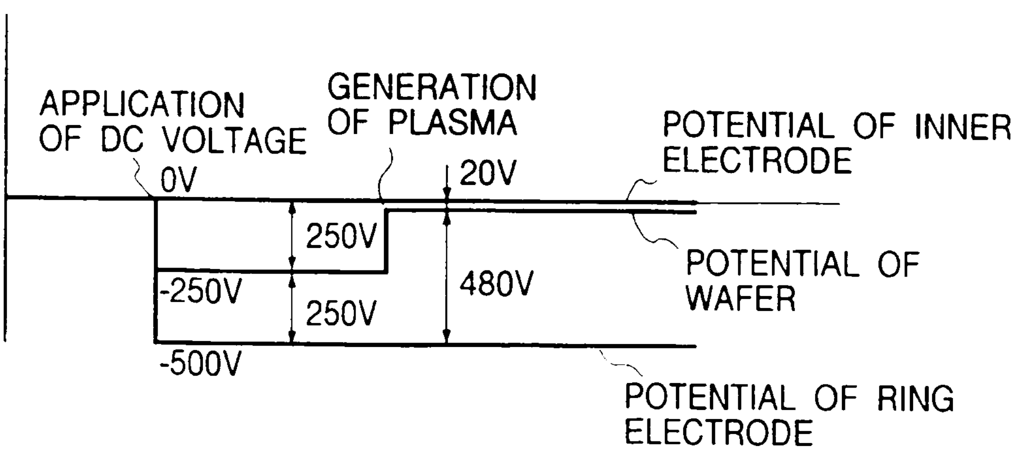

APPLICATION OF DC VOLTAGE
GENERATION OF PLASMA
POTENTIAL OF INNER ELECTRODE
0V
20V
250V
-250V
250V
480V
POTENTIAL OF WAFER
-500V
POTENTIAL OF RING ELECTRODE

FIG. 12

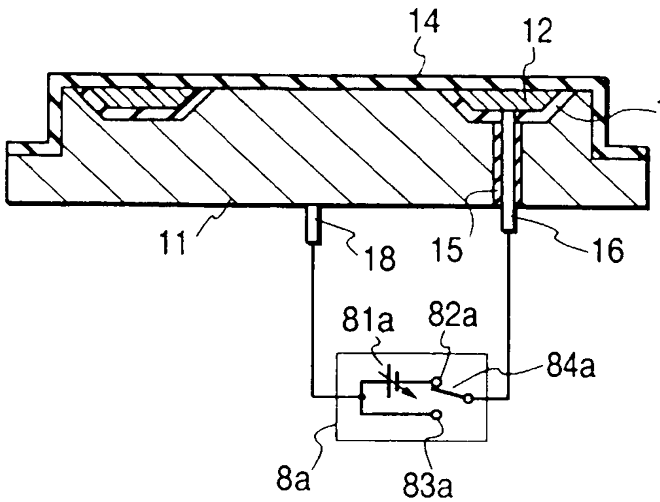

14
12
13
11
18
15
16
81a
82a
84a
8a
83a

FIG. 13

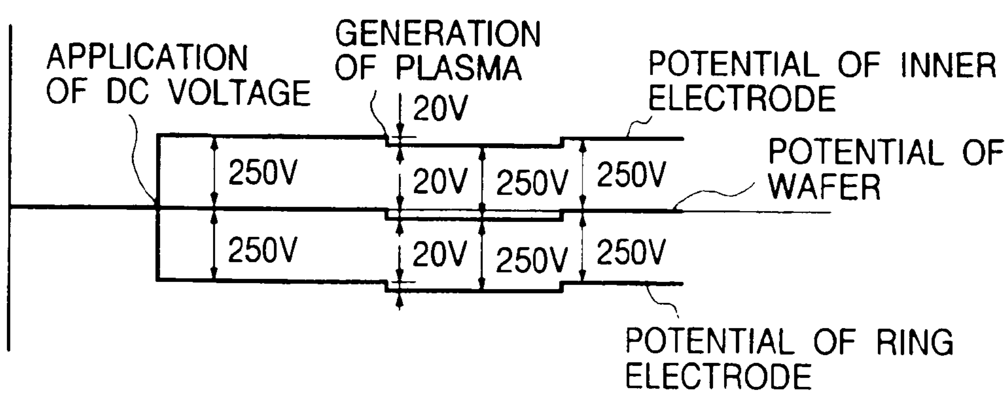

APPLICATION
OF DC VOLTAGE
GENERATION
OF PLASMA
20V
POTENTIAL OF INNER
ELECTRODE
250V
20V
250V
250V
POTENTIAL OF
WAFER
250V
20V
250V
250V
POTENTIAL OF RING
ELECTRODE

FIG. 14

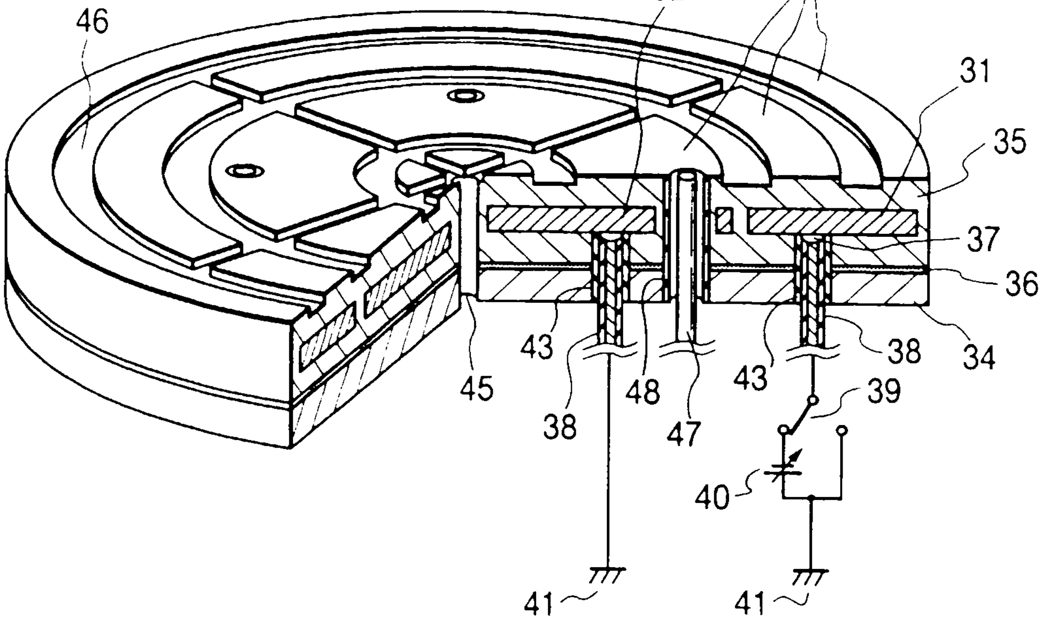


FIG. 15

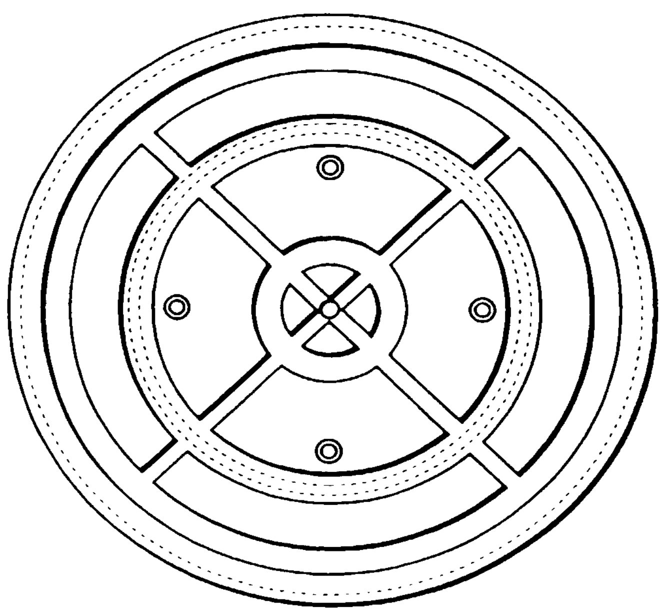


FIG. 16(a)

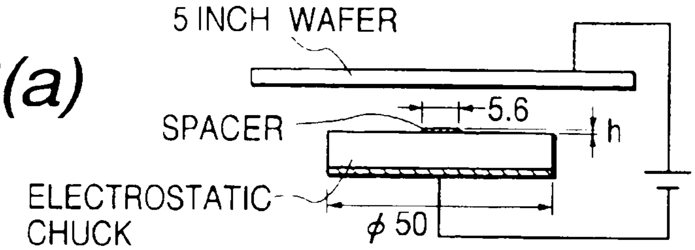


FIG. 16(b)

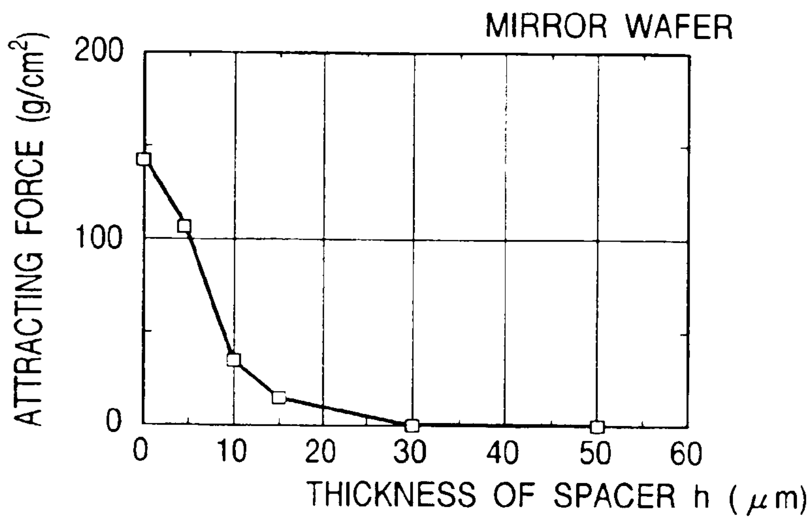


FIG. 16(c)

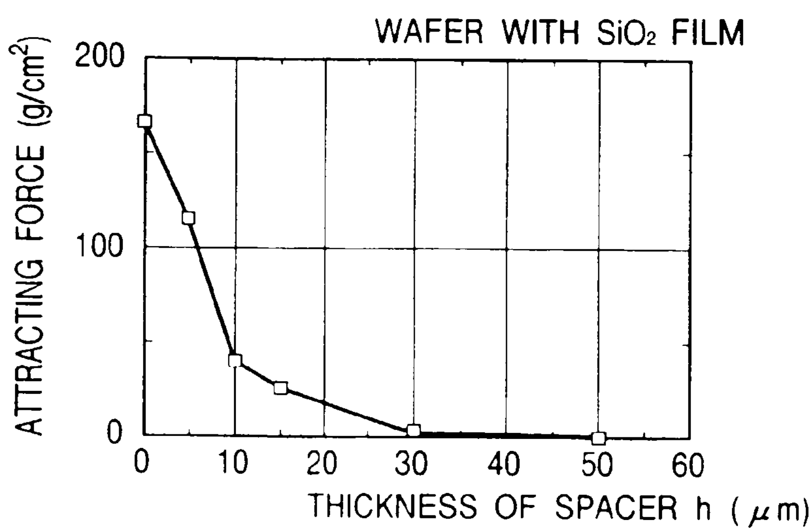
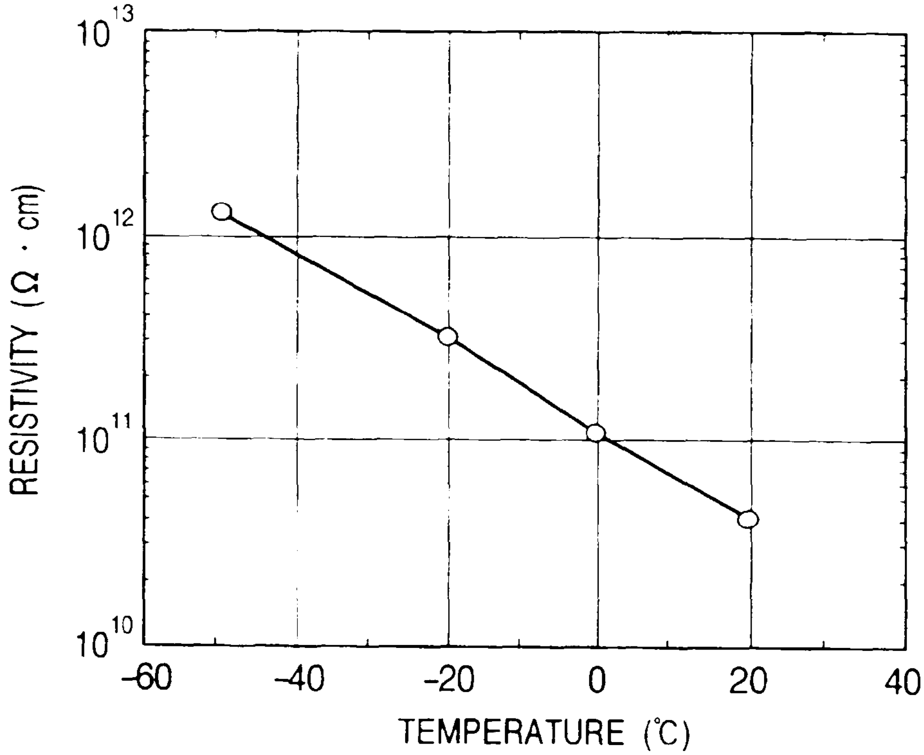


FIG. 17



10^{13}
10^{12}
10^{11}
10^{10}
RESISTIVITY ($\Omega \cdot cm$)
-60
-40
-20
0
20
40
TEMPERATURE (℃)

FIG. 18

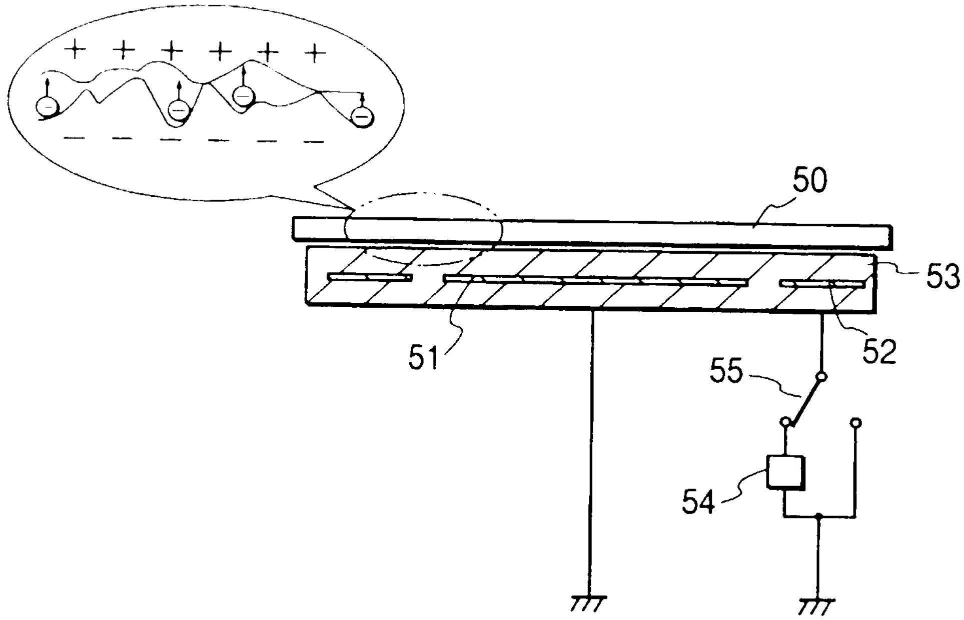


FIG. 19

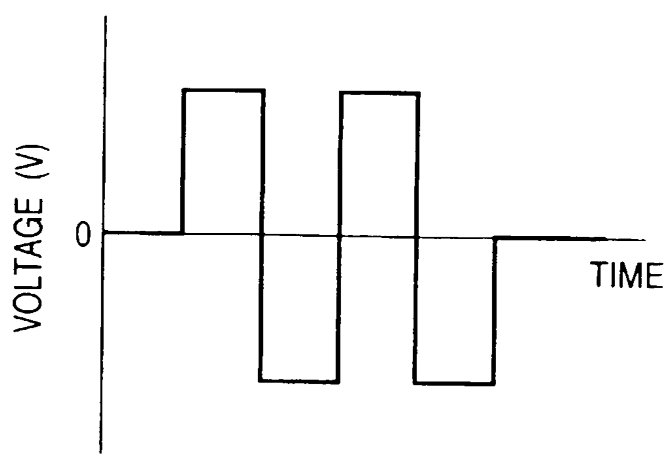


FIG. 20

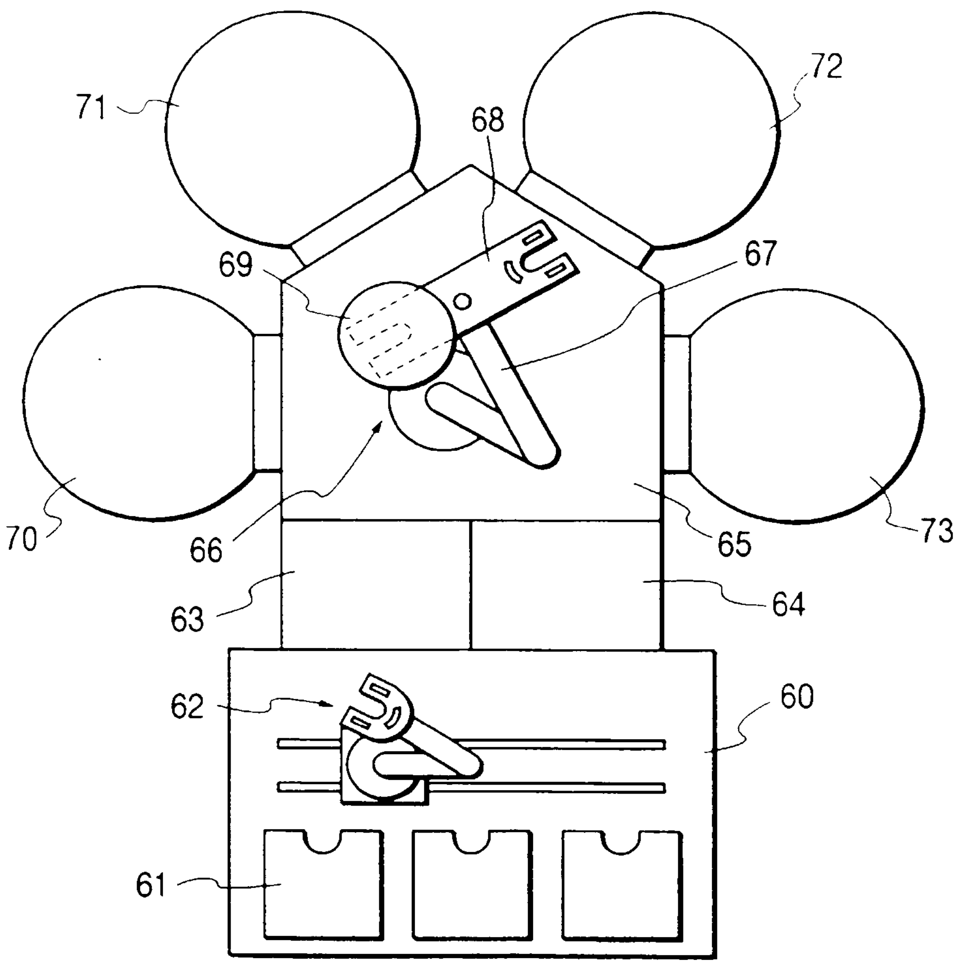

71
72
68
69
67
70
66
65
73
63
64
62
60
61

FIG. 21

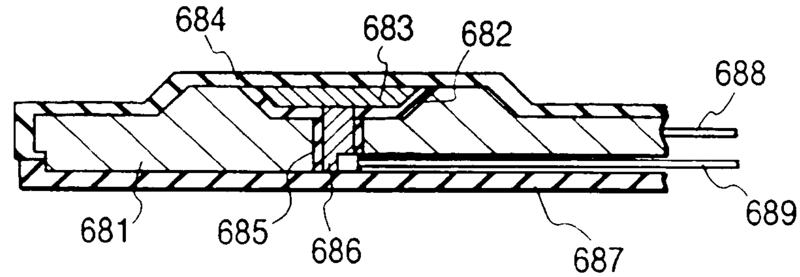

684
683
682
688
681
685
686
687
689

FIG. 22

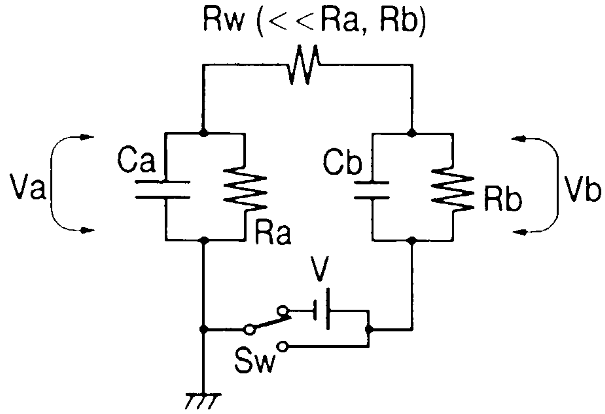

Rw (<<Ra, Rb)
Ca
Cb
Va
Vb
Ra
Rb
V
Sw

FIG. 23

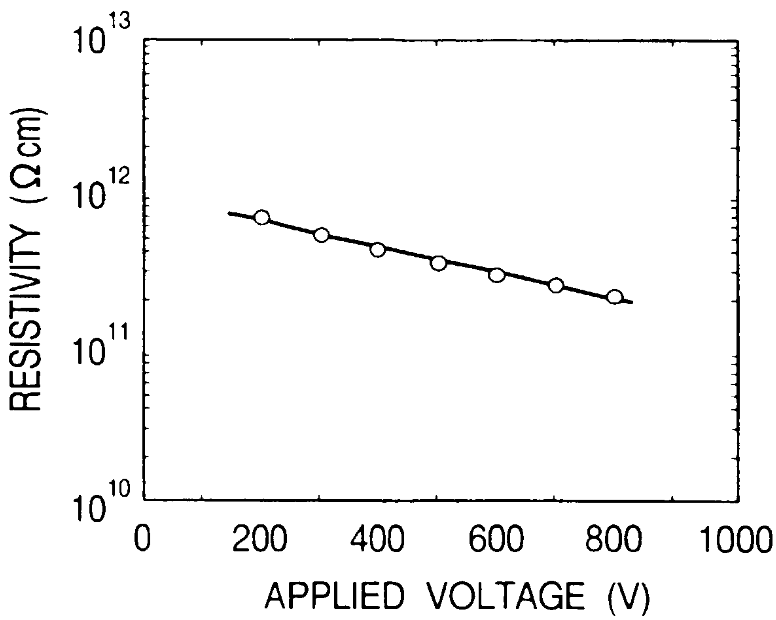

RESISTIVITY (Ωcm)
10^{13}
10^{12}
10^{11}
10^{10}
0
200
400
600
800
1000
APPLIED VOLTAGE (V)

FIG. 24(a)

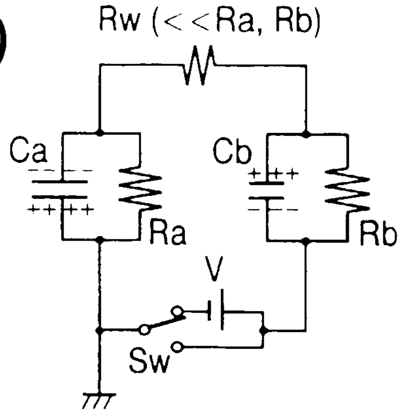


FIG. 24(b)

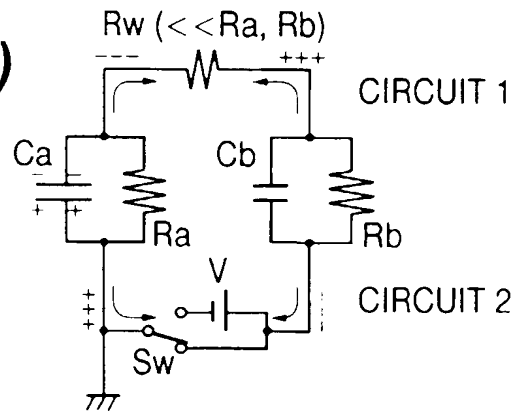


FIG. 24(c)

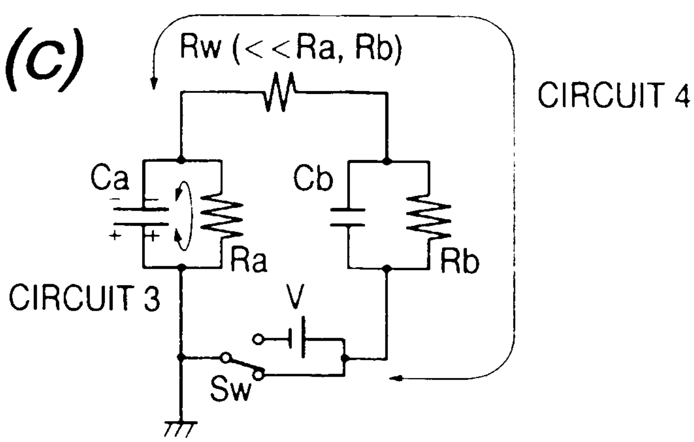
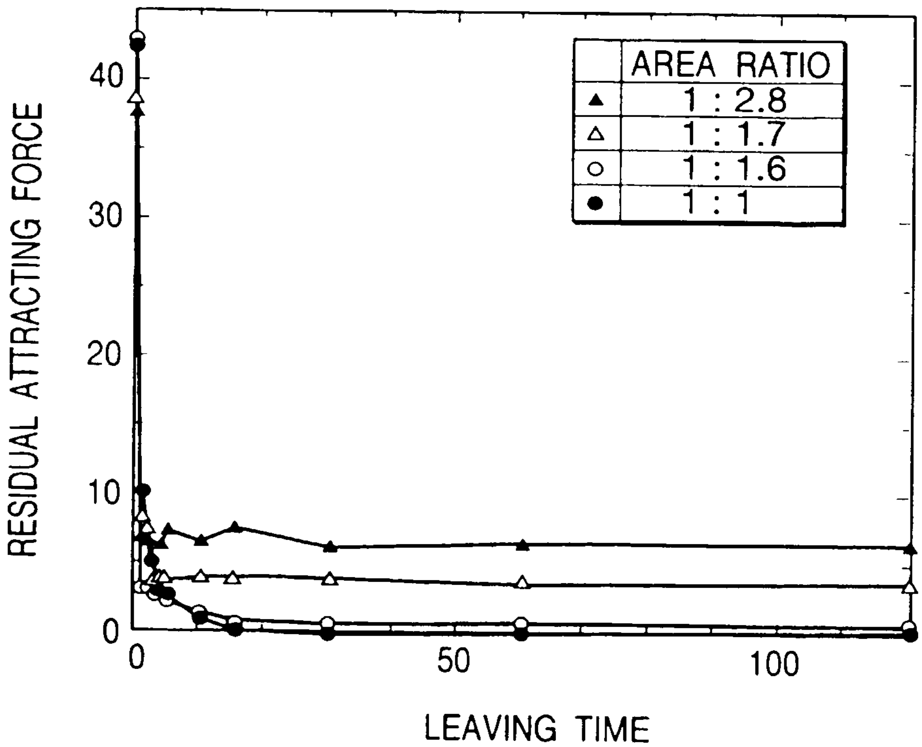


FIG. 25


AREA RATIO
1 : 2.8
1 : 1.7
1 : 1.6
1 : 1
RESIDUAL ATTRACTING FORCE
40
30
20
10
0
0
50
100
LEAVING TIME

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 831 526 A3

(12) **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:
15.03.2000 Bulletin 2000/11

(51) Int Cl.[7]: **H01L 21/68**

(43) Date of publication A2:
25.03.1998 Bulletin 1998/13

(21) Application number: **97307330.7**

(22) Date of filing: **19.09.1997**

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV RO SI

(30) Priority: **19.09.1996 JP 24753696**

(71) Applicant: **Hitachi, Ltd.**
Chiyoda-ku, Tokyo 101 (JP)

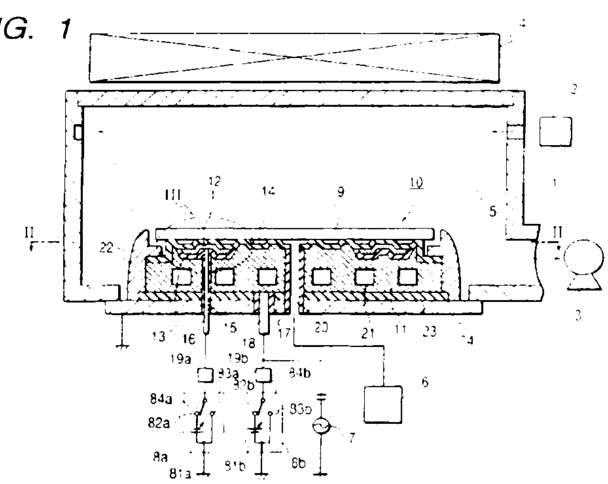
(72) Inventors:
- **Kanno, Seiichiro**
  Niihari-Gun, Ibaraki-Ken (JP)
- **Usui, Tatehito**
  Niihari-Gun, Ibaraki-Ken (JP)
- **Yoshioka, Ken**
  Hikari-Shi, Yamaguchi-Ken (JP)
- **Kanai, Saburo**
  Hikari-Shi, Yamaguchi-Ken (JP)
- **Itou, Youichi**
  Kudamatsu-Shi, Yamaguchi-Ken (JP)

(74) Representative:
Paget, Hugh Charles Edward et al
MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP (GB)

(54) **Electrostatic chuck, and method of and apparatus for processing sample using the chuck**

(57) An electrostatic chuck (10) has a pair of electrodes (11, 12) having different polarities; and a dielectric film (14), formed on top surfaces of the pair of electrodes, on which a sample is electrostatically attracted and held when a DC voltage is applied between the pair of electrodes; wherein amounts of electric charges stored on attracting portions of the dielectric film corresponding to the pair of electrodes directly before cessation of the DC voltage applied between the pair of electrodes are substantially equal to each other. With this chuck, the electric charges stored on the attracting portions of the dielectric film after cessation of the DC voltage can be eliminated due to the balance between the electric charges having different polarities. The electrostatic chuck thus achieves a significantly reduced residual attracting force of the sample.

FIG. 1



EP 0 831 526 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 7330

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X A	US 4 184 188 A (BRIGLIA DONALD D) 15 January 1980 (1980-01-15) * column 2, line 31 - column 4, line 2; figures 1-3 *	1,2 3-17	H01L21/68
X,D A	US 4 384 918 A (ABE NAOMICHI) 24 May 1983 (1983-05-24) * the whole document *	1,2 3-17	
P,X	EP 0 734 052 A (APPLIED MATERIALS INC) 25 September 1996 (1996-09-25) * column 5, line 41 - column 8, line 38; figures 2-5 *	1-17	
A	EP 0 360 529 A (TOTO LTD) 28 March 1990 (1990-03-28) * the whole document *	1-17	
A	US 5 099 571 A (LOGAN JOSEPH S ET AL) 31 March 1992 (1992-03-31) * column 3, line 40 - column 7, line 3; figures 1-8 *	1-17	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	US 5 535 090 A (SHERMAN ARTHUR) 9 July 1996 (1996-07-09) * the whole document *	1-17	H01L
A	US 5 452 177 A (FRUTIGER WILLIAM A) 19 September 1995 (1995-09-19) * the whole document *	1-17	
A	US 5 001 594 A (BOBBIO STEPHEN M) 19 March 1991 (1991-03-19) * the whole document *	1-17	
	-/--		

~~The present search report has been drawn up for all claims~~

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 October 1999	Kirkwood, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

Application Number
EP 97 30 7330

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-17

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 7330

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	HARTSOUGH L D: "ELECTROSTATIC WAFER HOLDING" SOLID STATE TECHNOLOGY, vol. 36, no. 1, 1 January 1993 (1993-01-01), pages 87-90, XP000344005 ISSN: 0038-111X * page 88, left-hand column, paragraph 4 - page 89, right-hand column, paragraph 3; figures 2-5 * ---	1-17	
A	DAVIET J -F ET AL: "ELECTROSTATIC CLAMPING APPLIED TO SEMICONDUCTOR PLASMA PROCESSING I. THEORETICAL MODELING" JOURNAL OF THE ELECTROCHEMICAL SOCIETY, vol. 140, no. 11, 1 November 1993 (1993-11-01), pages 3245-3256, XP000424496 ISSN: 0013-4651 * page 3248, right-hand column, paragraph 2 - page 3251, left-hand column, paragraph 1; figure 5; tables III-IV * -----	1-17	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

~~The present search report has been drawn up for all claims~~

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 October 1999	Kirkwood, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

LACK OF UNITY OF INVENTION
SHEET B

Application Number
EP 97 30 7330

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims: 1-17

   Claims 1-17 relate to an electrostatic chuck and a sample processing method wherein amounts of charge on the electrodes are balanced by, for instance, ensuring the electrode areas are approximately equal.

2. Claim : 18

   Claim 18 relates to a sample processing method involving a sequence of steps for operating an electrostatic chuck and eventually removing the sample from the chuck.

3. Claims: 19-20

   Claims 19-20 relate to a sample processing apparatus comprising an electrostatic chuck having amongst other things an insulating film composed of a thermal spray film.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 97 30 7330

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

14-10-1999

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4184188 A	15-01-1980	EP 0007918 A	06-02-1980
		IL 64648 A	30-03-1984
		JP 55500049 T	31-01-1980
		WO 7900510 A	09-08-1979
US 4384918 A	24-05-1983	JP 1153069 C	30-06-1983
		JP 57044747 B	22-09-1982
		JP 57060074 A	10-04-1982
		JP 1052899 B	10-11-1989
		JP 1602739 C	29-03-1991
		JP 57064950 A	20-04-1982
		EP 0049588 A	14-04-1982
		IE 52318 B	16-09-1987
EP 0734052 A	25-09-1996	US 5822171 A	13-10-1998
		DE 69502087 D	20-05-1998
		DE 69502087 T	17-09-1998
		EP 0734053 A	25-09-1996
		JP 9022936 A	21-01-1997
		JP 9022937 A	21-01-1997
		US 5801915 A	01-09-1998
EP 0360529 A	28-03-1990	JP 2160444 A	20-06-1990
		JP 2665242 B	22-10-1997
		AT 154163 T	15-06-1997
		CA 1313428 A	02-02-1993
		DE 68928094 D	10-07-1997
		DE 68928094 T	02-10-1997
		US 5151845 A	29-09-1992
US 5099571 A	31-03-1992	US 5055964 A	08-10-1991
		EP 0473930 A	11-03-1992
		JP 6342843 A	13-12-1994
		JP 8017201 B	21-02-1996
US 5535090 A	09-07-1996	WO 9524070 A	08-09-1995
		US 5867359 A	02-02-1999
US 5452177 A	19-09-1995	DE 69316872 D	12-03-1998
		DE 69316872 T	28-05-1998
		EP 0620953 A	26-10-1994
		JP 7506465 T	13-07-1995
		WO 9411944 A	26-05-1994
		EP 0460955 A	11-12-1991
US 5001594 A	19-03-1991	WO 9103833 A	21-03-1991

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

(19)日本国特許庁（JP）　(12) **公開特許公報**（A）　(11)特許出願公開番号

特開平4−371579

(43)公開日　平成4年(1992)12月24日

(51)Int.Cl.^{5}		識別記号	庁内整理番号	FI	技術表示箇所
C23C	14/50		8414−4K		
H01L	21/203	S	8422−4M		
	21/68	R	8418−4M		

審査請求　未請求　請求項の数4（全 7 頁）

(21)出願番号　特願平3−117062

(22)出願日　平成3年(1991)6月19日

(71)出願人　000231464
日本真空技術株式会社
神奈川県茅ケ崎市萩園2500番地

(72)発明者　牧　正人
神奈川県茅ケ崎市萩園2500番地　日本真空技術株式会社内

(74)代理人　弁理士　北村　欣一　（外3名）

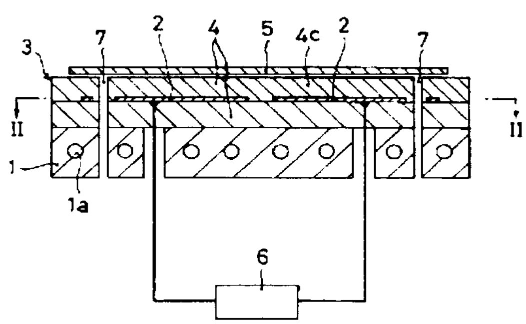
(54)【発明の名称】　静電吸着装置

(57)【要約】　　（修正有）

【目的】静電チャックの被処理物吸着面に設けたガス導入孔から被処理物の熱を静電チャックへ伝達するヘリウムガスを導入した場合、被処理物の外周部が冷却されにくくなる欠点を解決すること

【構成】基体1により冷却された静電チャック3の吸着面に設けた被処理物5の熱を該静電チャックへ伝達するガスを噴出するガス導入孔7を、被処理物の吸着面の外周寄りに少なくとも2か所以上設けるか、該ガス導入孔の開口部を上記吸着面の外周付近に沿った溝で形成し、更に上記静電チャックにより被処理物に作用する吸着力を、ガス導入孔から噴き出すガスにより該被処理物に生じる力よりも大きく制御した

【効果】静電チャックに吸着した被処理物を均一な低い温度に冷却することができる



【特許請求の範囲】

【請求項1】　冷却機構を有する基体に、被処理物を静電的に吸着固定する絶縁物により覆われた少なくとも1対の電極から成る静電チャックを接着し、該静電チャックの吸着面に、これに吸着した被処理物の熱を静電チャックへ伝達するためのガスを噴出するガス導入孔を設けた静電吸着装置に於いて、該ガス導入孔は被処理物の吸着面の外周寄りに少なくとも2か所以上設けられていることを特徴とする静電吸着装置。

【請求項2】　上記ガス導入孔は、上記吸着面の外周付近に沿った溝で形成されていることを特徴とする請求項1に記載の静電吸着装置。

【請求項3】　上記ガス導入孔は、該静電チャック内に設けた環状の溝孔に連通して形成されていることを特徴とする請求項1に記載の静電吸着装置。

【請求項4】　上記静電チャックにより被処理物に作用する吸着力を、ガス導入孔から噴き出すガスにより該被処理物に生じる力よりも大きく制御することを特徴とする請求項1又は2又は3に記載の静電吸着装置。

【発明の詳細な説明】

【0001】

【産業上の利用分野】この発明は、被処理物を静電的に基体に吸着して例えばスパッタリングの処理を施すために使用され、特に被処理物と基体との間で均一で良好な熱伝導性を得るに適した静電吸着装置に関する。

【0002】

【従来の技術】従来、種々の静電吸着装置が知られており、その一例として、例えば図11に示すように、冷却水配管等の冷却機構1aを備えた基体1の上部の被処理物5を静電的に固定する静電チャック3を、直流電源6に接続した電極2と、該電極2の下部の基体1に貼着した絶縁物4aと該電極2の上部の被処理物5に密着するゴム状の絶縁物4bで構成したものが知られている。

【0003】また、図12に示すように、冷却機構1aを備えた基体1の上部の被処理物5を静電的に固定する静電チャック3を、直流電源6に接続した電極2とこれを覆うセラミックス等の絶縁物4とで構成し、該静電チャック3の被処理物5の吸着面の中心付近に絶縁物4及び基体1を貫通したガス導入孔7を1カ所に開口させ、該ガス導入孔7から被処理物5と絶縁物4との隙間にガスを流すようにしたものも知られている（特開平3－3219号公報）。

【0004】上記図11に示したものは、まず被処理物5を静電チャック3に載せ、電極2に電圧を印加する＊

＊と、被処理物5に

$$F=\varepsilon\cdot(S/d^2)\cdot(V/2)^2$$

なる吸引力が働き、被処理物5がゴム状の絶縁物4に密着する。ここで、εはゴム状絶縁物4bの誘電率、dはゴム状絶縁物4bの厚み、Sは電極2の被処理物5に対向する面の面積、Vは直流電源6の電圧である。次に、熱伝導性の良いアルミニウム等の金属でできた基体1を冷媒の循環等により冷却機構1aで冷却すると、被処理物5の熱がゴム状絶縁物4bと絶縁物4aを介して基体1に伝達され、被処理物の冷却が行われる。したがって、例えば被処理物5にエッチング処理を行なう場合、エッチングプラズマの熱負荷が被処理物5にかかっても、被処理物の温度を低く保つことができる。しかしながら、この時、ゴム状絶縁物4bが反応性のエッチングガス等に侵されて変質したり、その処理後に直流電源6を切り被処理物5を静電チャック3から取り外す際に被処理物5がゴム状絶縁物に粘着して剥がれ難くなる問題が起きる。

【0005】図12に示した従来例では、被処理物5が載置される静電チャック3の絶縁物4に例えばセラミックスのような堅い材料が使用されているので上記の如き問題は生じることがないが、電極2に電圧を印加して絶縁物4の上に被処理物5を吸着固定した場合、例えばアルミニウム製の基体1を冷却機構1aで冷却すると熱伝導により絶縁物4を冷却することができても、被処理物5は絶縁物4が堅いために絶縁物4と点接触状態で接触するため、平均10μ程度の間隔が被処理物と絶縁物との間に存在し、被処理物5の熱が絶縁物4に伝達されにくい。そこで、更に静電チャック3の被処理物5の吸着面域内に設けられたガス導入孔7から上記隙間にガスを流し、ガスを介して被処理物の熱を絶縁物に伝達して被処理物を冷却するようにしている。したがって、例えばエッチングプラズマなどの熱負荷が被処理物にかかっても、被処理物の温度を低く保つことができる。

【0006】

【発明が解決しようとする課題】上記のような被処理物を冷却する一手段として被処理物と絶縁物の隙間にガスを流す形式の静電吸着装置に於いては、隙間がガスの平均自由行程より小さいか同じ程度のとき、単位面積当たりの熱伝達Qは次式のようになる。

【0007】

$$Q=(3/2)\cdot\kappa\cdot\alpha_1\cdot(T-Tg)\cdot\Gamma$$

ただし

$$\begin{aligned}\Gamma&=(1/4)\cdot n\cdot \upsilon\\&=(1/4)\cdot P/(\kappa\cdot Tg)\cdot\{8\cdot\kappa\cdot Tg/(\pi\cdot m)\}^{1/2}\end{aligned}$$

$$Tg=(\alpha_1\cdot T+\alpha_2\cdot T_0)/(\alpha_1+\alpha_2)$$

である。

【0008】ここで、κはボルツマン定数、α_1は静電チャックの被処理物吸着面に対するガス分子の熱的適応係数、Tは被処理物の温度、T_0は絶縁物の温度、Tgはガス分子の温度、Γは静電チャックの被処理物吸着面

に入射するガス分子の面密度、nはガス分子の密度、υはガス分子の平均速度、mはガス分子の質量、Pは静電チャックの被処理物吸着面のガスの圧力をそれぞれ表している。

【0009】上記の式から、単位面積当たりの熱伝達Qは、静電チャックの被処理物吸着面のガス圧力Pに比例することがわかる。従来の静電吸着装置では、被処理物吸着面の中心付近のガス導入孔から例えば10Torr程度のヘリウムガスを導入した場合、ガス導入孔の開口部から被処理物の外周に向かって圧力降下が起きるため、被処理物の外周部が冷却されにくくなるという問題があった。例えば、被処理物が6インチウエハで、ガス導入孔が被処理物吸着面の中心に1カ所ある場合のガスの圧力分布は、図13のようになる。ここで、ガス導入孔でのヘリウムガスの圧力は10Torr、ウエハ周囲の雰囲気は0．01Torrである。この状態でウエハに例えば1．18W／cm^{2}の熱負荷をかけた場合、ウエハ内の熱伝導を考慮してもウエハの温度分布は図14のようになり、中心付近と外周部で温度差が大きくなる。この温度差は、熱負荷が大きくなればなるほど大きくなり、例えばドライエッチングでは選択性やエッチング形状が均一でなくなる不都合をもたらす。

【0010】本発明は、このような問題を解決し、被処理物吸着面の熱伝導性が均一になる静電吸着装置を提供することを目的とするものである。

【0011】

【課題を解決するための手段】上記の目的を達成するために、本発明では、冷却機構を有する基体に、被処理物を静電的に吸着固定する絶縁物により覆われた少なくとも1対の電極から成る静電チャックを接着し、該静電チャックの吸着面に、これに吸着した被処理物の熱を静電チャックへと伝達するためのガスを噴出するガス導入孔を設けた静電吸着装置に於いて、該ガス導入孔は被処理物の吸着面の外周寄りに少なくとも2か所以上設けられているか、もしくは、上記ガス導入孔の開口を、上記吸着面の外周付近に沿った溝状に形成するか或いは該静電チャック内に設けた溝孔に連通させて形成し、更には上記静電チャックにより被処理物に作用する吸着力を、ガス導入孔から噴き出すガスにより該被処理物に生じる力よりも大きく制御するようにした。

【0012】

【作用】ガス導入孔から噴出するガスは、静電チャックの吸着面に吸着した被処理物と絶縁物との隙間に拡散するが、該ガス導入孔は該吸着面の外周寄りに少なくとも3カ所設け、或いは該ガス導入孔を吸着面の外周付近に沿った溝形に形成すると、被処理物と吸着面の間に流れるガスの圧力分布は均一になり、そのため被処理物の中心部と周辺部の温度差が少なくなって、例えばドライエッチングの選択性やエッチング形状の均一性が向上する。またこのとき、静電チャックの電圧を制御し、ガス導入孔から噴出するガスにより被処理物が受ける力よりも静電チャックの吸着力を大きくしておくと、被処理物と吸着面との隙間が最小に保持されその間を流れるガスの圧力が高まって一層圧力分布が均一化される。

【0013】

【実施例】本発明の実施例を図面に基づき説明すると、図1及び図2はドライエッチング装置の真空室内に設けた静電吸着装置の実施例を示し、この例では、冷却水配管等の冷却機構1aを備えたアルミニウム製の基体1の上部に、アルミナ製の絶縁物4で一対の半円形円板状の電極2を覆って構成した静電チャック3が設けられ、各電極2に直流電源6から電位が与えられると該静電チャック3に静電気が発生してその表面に6インチウエハ等の被処理物5が吸着される。該静電チャック3の背面は基体1に貼着され、電極2の上面を覆う絶縁物4cの厚さを0．3mmとし、一対の電極2の直径を被処理物5の直径よりも多少小さい程度に構成した。該基体1と静電チャック3の表裏を貫通して例えばヘリウムガスを導入するガス導入孔7が、被処理物5の吸着面の外周から10mm程度内側に均等の間隔を存して円形に12カ所設けられ、該ガス導入孔7の開口端部から噴出するヘリウムガスが被処理物5と静電チャック3の吸着面との隙間を流れる。

【0014】図3及び図4に示す実施例は、図1及び図2に示した実施例とガス導入孔7の数と形状が異なり、図3及び図4の例では、ガス導入孔7を2個とし、その開口端部を静電チャック3の吸着面の外周から10mm程度内側に設けた半円弧状の溝8で形成した。この場合、該ガス導入孔7から噴出するヘリウムガスは溝8を介して被処理物5と静電チャックの吸着面との隙間を流れる。

【0015】図1及び図2の実施例に於いて、被処理物5を静電チャック3の上に載せた後電極2に電圧を印加すると、被処理物5が静電チャック3の静電気により吸着固定される。次いで基体1を冷却機構1aで冷却すると、熱伝導により絶縁物4が冷却され、更にガス導入孔7からヘリウムガスを噴出させると、被処理物5の熱がヘリウムガスを介して絶縁物4に伝達され、被処理物5が冷却される。このときの吸着面に於けるヘリウムガスの圧力分布は図5に示す如くとなり、吸着面の中心部からその外周近傍まで7．2Torrのヘリウム圧力が保たれる。この場合のガス導入孔7でのヘリウムガスの圧力は10Torr、被処理物5の周囲の雰囲気は0．01Torrで、雰囲気に洩れ出すヘリウムの流量は2．26×10^{2}Torr・リットル／secである。被処理物5のウエハをエッチング処理するために、被処理物5に均一に1．18W／cm^{2}の熱負荷がかかった場合の被処理物5の温度分布は図6に示す如くとなり、被処理物5の中心部から外周部にかけての温度は低く保たれている。このときのヘリウムガス圧力により被処理物5に発生する力は1

5．0Nであったので、電極2に3000Vの電圧を印加し、静電チャック3の吸着力を18．7Nに制御して静電チャック3と被処理物5との隙間を一定に保持し、ヘリウムガス圧力の低下を防止して被処理物5の温度が不均一にならないようにした。

【0016】図3及び図4の実施例では、静電チャック3の吸着面に於ける圧力分布は図7のようになり、中心部から外周近傍まで7．2Torrのヘリウム圧力が保たれている。この場合の溝8に於けるヘリウムガスの圧力は7．2Torr、被処理物5の周囲の雰囲気は0．01Torrで、雰囲気に洩れ出すヘリウムの流量は2．11×10[illegible] Torr・リットル／sec である。また被処理物5の温度分布は図8のようになり、被処理物5の中心部及び外周部の温度は低く保たれている。このときのヘリウムガスの圧力により被処理物5が受ける力は14．7Nであるので、電極2に3000Vの電圧を印加して18．7Nの吸着力に制御した。

【0017】図9及び図10に示す実施例では、静電チャック3の内部に環状の溝孔9を形成してこれに各ガス導入孔7を連通させ、該溝孔9を介してヘリウムガスが噴出するようにした。

【0018】尚、これらの実施例に於いて電極2にかける電圧を3000Vとしたのは、絶縁物4の絶縁耐圧に起因するもので、これ以上の電圧を印加すると絶縁性が損なわれるからであり、絶縁耐圧を越えないような吸着力で被処理物を吸着できるようにヘリウムガスの圧力が制御される。

【0019】該絶縁物4には熱伝導の良いセラミックスや樹脂を使用しても良く、またガス導入孔7と溝8の位置は、ヘリウムガスの洩れ量が問題にならないときは、更に吸着面の外周寄りに設けることもできる。被処理物5はウエハ以外のものであってもよい。また、静電チャック3を縦置きして吸着面を側方に向け、或は吸着面を下面に向けて逆置きし、下側に吸着することも可能である。

【0020】

【発明の効果】以上のように本発明においては、被処理物の熱を冷却された静電チャックへ伝達するガスを噴出するガス導入孔を静電チャックの被処理物の吸着面の外周寄りに少なくとも2か所以上設けるか、或いはガス導入孔を上記吸着面の外周付近に沿った溝で形成したので、ガスを静電チャックと被処理物の隙間に均一な圧力で流通させることができ、その結果被処理物を均一な低い温度に冷却することができ、静電チャックにより被処理物に作用する吸着力を、ガス導入孔から噴き出すガスにより該被処理物に生じる力よりも大きく制御すると、流通するガスの圧力が高まって被処理物の温度を均一で低温に制御できる等の効果がある。

【図面の簡単な説明】

【図1】　本発明の実施例の截断側面図

【図2】　図1のII－II線部分の截断平面図

【図3】　本発明の他の実施例の截断側面図

【図4】　図3のIV－IV線部分の截断平面図

【図5】　図1に示した実施例のヘリウムガスの圧力分布図

【図6】　図1に示した実施例に於ける被処理物の温度分布図

【図7】　図3に示した実施例のヘリウムガスの圧力分布図

【図8】　図3に示した実施例に於ける被処理物の温度分布図

【図9】　本発明の更に他の実施例の截断側面図

【図10】図9のX－X線部分の截断平面図

【図11】従来例の截断側面図

【図12】他の従来例の截断側面図

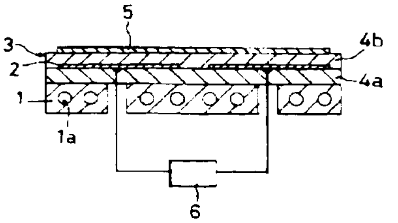
【図13】図12の従来例に於けるヘリウムガスの圧力分布図

【図14】図12の従来例に於ける被処理物の温度分布図

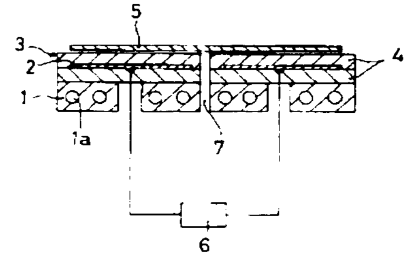
【符号の説明】

1	基体	1a	冷却機構
2	電極	3	静電チャック
4、4a、4b	絶縁物	5	被処理物
6	直流電源	7	ガス導入孔
8	溝	9	溝孔

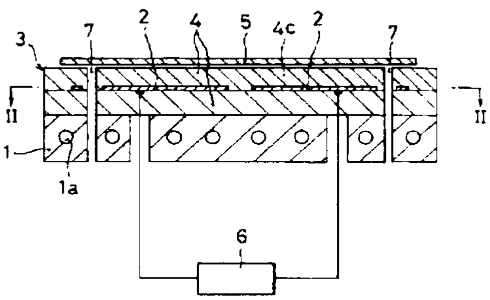
【図11】



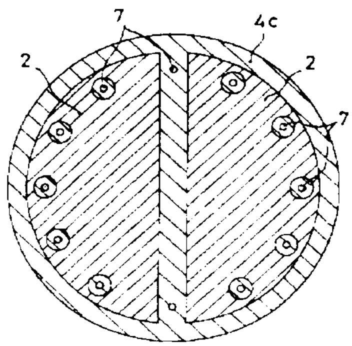
【図12】



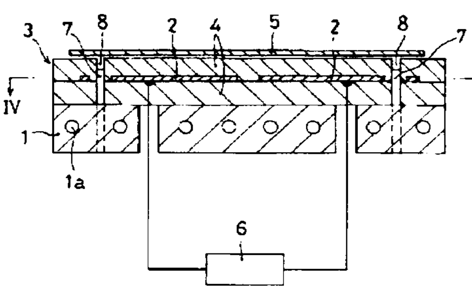
【図1】



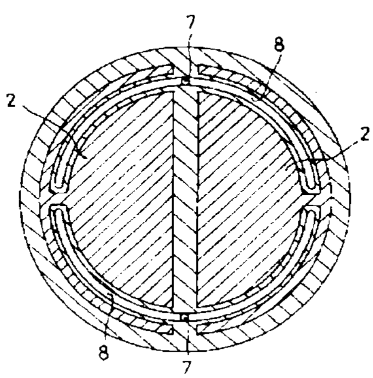
【図2】



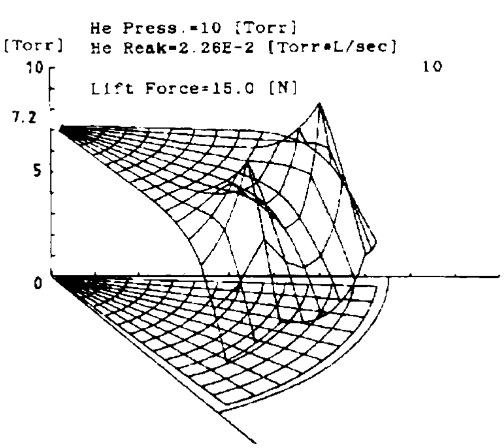
【図3】



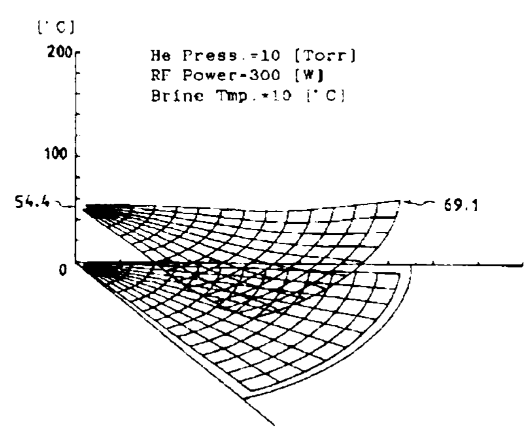
【図4】



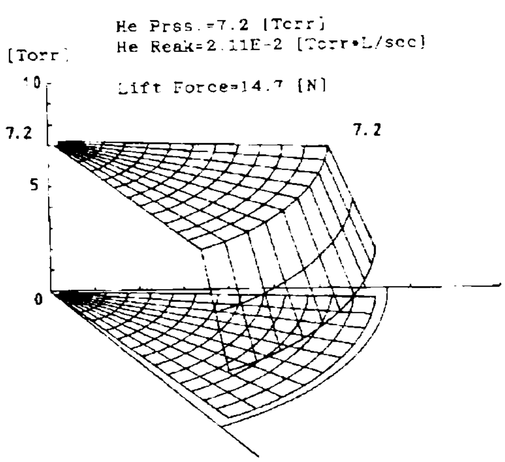
【図5】



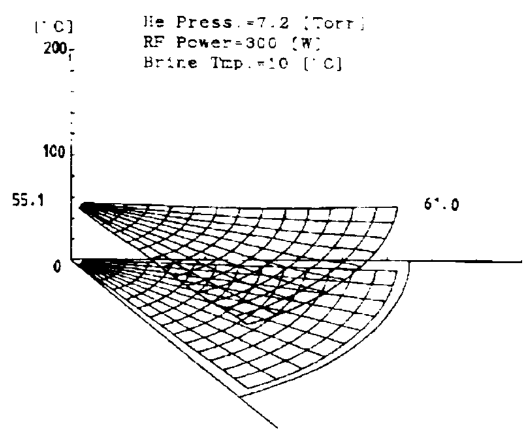
【図6】



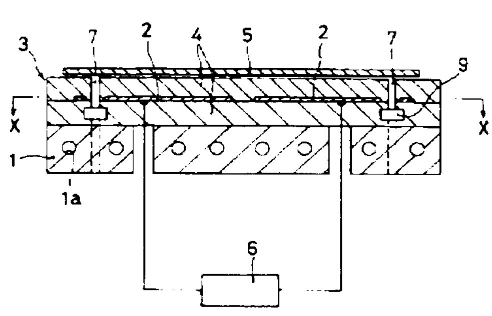
【図7】


He Prss.=7.2 [Torr]
He Reak=2.11E-2 [Torr•L/sec]
Lift Force=14.7 [N]
[Torr]
10
7.2
5
0
7.2

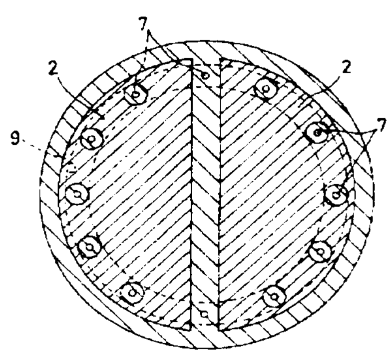
【図8】


[°C]
200
100
55.1
0
He Press.=7.2 [Torr]
RF Power=300 [W]
Brine Tmp.=10 [°C]

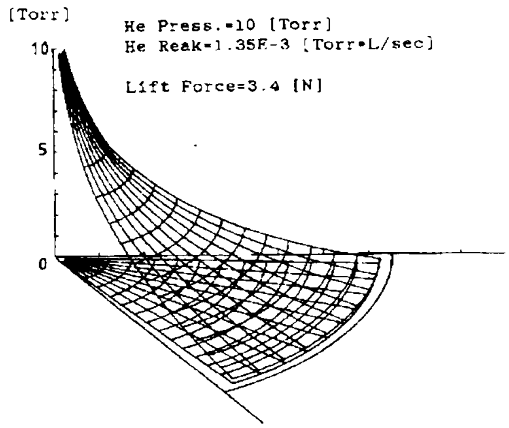
【図9】


3
7
2
4
5
2
7
9
X
X
1
1a
6

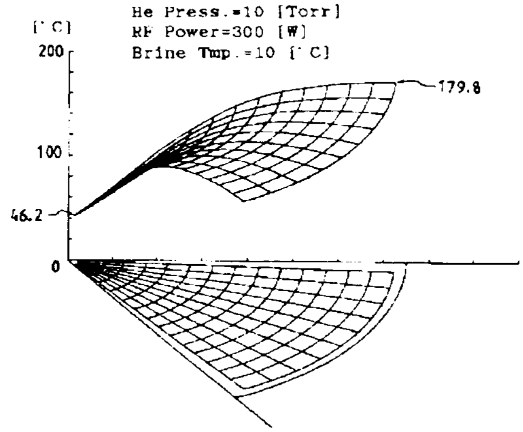
【図10】


7
2
2
9
7

【図13】


[Torr]
He Press.=10 [Torr]
He Reak=1.35E-3 [Torr•L/sec]
Lift Force=3.4 [N]
10
5
0

【図14】


He Press.=10 [Torr]
RF Power=300 [W]
Brine Tmp.=10 [°C]
[°C]
200
100
46.2
0
179.8

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01L

A2

(11) International Publication Number: WO 96/13058

(43) International Publication Date: 2 May 1996 (02.05.96)

(21) International Application Number: PCT/US95/13158

(22) International Filing Date: 17 October 1995 (17.10.95)

(30) Priority Data:
08/323,764 17 October 1994 (17.10.94) US

(71) Applicant: DIAMOND SEMICONDUCTOR GROUP, INC. [US/US]; 14 Blackburn Center, Gloucester, MA 01930 (US).

(72) Inventor: WHITE, Nicholas, R.; 21 Friend Court, Wenham, MA 01984 (US).

(74) Agents: LAHIVE, John, A., Jr. et al.; Lahive & Cockfield, 60 State Street, Boston, MA 02109 (US).

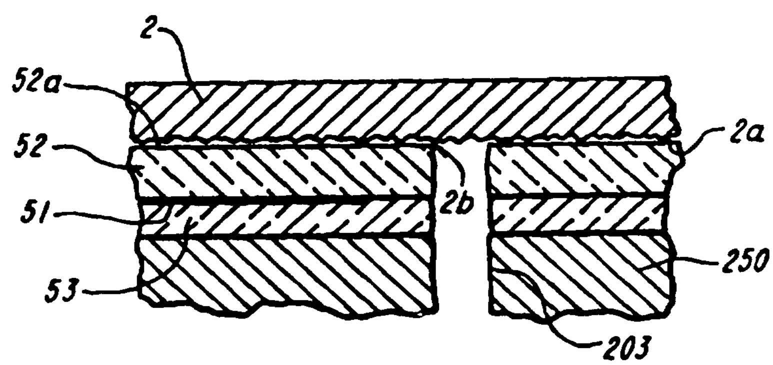
(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: APPARATUS AND METHOD FOR TEMPERATURE CONTROL OF WORKPIECES IN VACUUM

(57) Abstract

A flat workpiece is placed in contact with a flat platen in a vacuum chamber, and is held by a uniformly-distributed force while a small mass flow of gas is introduced along a contour to form a uniform pressure region between the flat workpiece and the platen. Separation of the two surfaces due to aplanarity or surface roughness is less than the gas mean free path, and high rates of heat transfer are obtained uniformly over the area of the workpiece. A scavenging port, located outwardly of the gas introduction contour is differentially pumped to reduce the rate of gas leakage into the chamber. Preferably, pressure is provided by an electrostatic clamp (for non-insulating substrates) or other clamping arrangement which does not occlude the front surface of the workpiece. In the electrostatic clamp, the voltage activation sequence prevents workpiece vibration, while a clamping current sensor immediately detects degree of contact, e.g., due to debris on the platen, and initiates a suitable warning or control. High cooling rates, freedom from bowing or stress, and full utilization of front surface area are all achieved.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgystan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo			SE	Sweden
CH	Switzerland	KR	Republic of Korea	SI	Slovenia
CI	Côte d'Ivoire	KZ	Kazakhstan	SK	Slovakia
CM	Cameroon	LI	Liechtenstein	SN	Senegal
CN	China	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
CZ	Czech Republic	LV	Latvia	TJ	Tajikistan
DE	Germany	MC	Monaco	TT	Trinidad and Tobago
DK	Denmark	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	US	United States of America
FI	Finland	ML	Mali	UZ	Uzbekistan
FR	France	MN	Mongolia	VN	Viet Nam
GA	Gabon				

APPARATUS AND METHOD FOR TEMPERATURE CONTROL OF WORKPIECES IN VACUUM

Background of the invention

The present invention relates to temperature control of a workpiece being processed on a treatment stage in a vacuum chamber, and more specifically to gas-assisted cooling of workpieces such as semiconductor wafers or flat-panel displays undergoing processes such as ion implantation in vacuum, or to gas-assisted cooling or heating of the workpieces undergoing similar processing.

During the doping of silicon wafers by ion implantation in the manufacture of microelectronic circuits, energy of up to several hundred joules per square centimeter is deposited in a thin silicon wafer. For commercial reasons, this energy must be deposited in a short time interval, so the processes require the wafer temperature to be controlled in a range, depending on the process, which is typically below 100° Celsius. Thus some means of heat removal is generally necessary. Historically, high-current ion implantation has been performed in batches of up to 25 wafers, with each wafer carried or rotated in front of the beam during a sequence of brief sub-intervals of the treatment cycle. This arrangement reduces the average heating rate and allows modest heat removal rates naturally occurring through radiation and conductive contact with the carrier to maintain acceptably low wafer temperatures. In some implanters and for many other processes, however, the wafers are processed one at a time mechanically clamped against a cooled platen. Sometimes gas is introduced behind the wafer to enhance heat removal from the wafer, as described in U.S. patent 4,261,762, of inventor King, and in some processes the wafer may even be actively heated by similar means. For gas cooling, a full-ring or multi-point clamp presses the wafer against a sealing ring formed of an elastomer. In one process of this type, as described in U.S. Patent No. 4,457,359, of inventor Holden, the pressure of the cooling gas causes the wafer to become domed. Such doming is undesirable because the spacing of the wafer from the platen is difficult to control and the gas cooling is strongly dependent on this spacing. Furthermore, doming introduces stress in the wafer that may cause damage, and it causes a variation in the angle of incidence of the ions at the wafer surface due to the curvature of the wafer, which in turn may cause other undesirable process variations. It is therefore preferable to mount or otherwise maintain the wafer flat.

It is also desirable, however, to avoid contacting the front side of the wafer with a clamp, since a clamp masks part of the wafer from the processing, and this wastes a portion of the wafer material. Clamping also causes local stresses which may lead to damage or breakage, and can generate particles which interfere with proper processing, and can cause

particles or debris to become embedded in the wafer. Front surface clamps may also be struck by the ion beam, or exposed to other processes, and are therefore a source of sputter contamination.

Most preferably, one would cool the backside of the wafer without causing any significant deformation of the wafer, apply a fairly uniform pressure over the full surface of the wafer, and avoid clamping with a concentrated force at the periphery. However it is essential to keep the rate of leakage of gas from the backside of the wafer at a level well below other sources of gas which already compromise the quality of the vacuum and present a load on the pumping systems, and it is also desirable, if leakage must occur, to tightly control the leakage of gas. There is thus generally a trade-off between process effectiveness, on the one hand, and the use of clamping or gas cooling on the other hand, which would limit application of gas cooling to relatively high pressure processes, such as RF sputtering.

Summary and Objects of the Invention

It is therefore an object of this invention to heat or cool a workpiece undergoing processing in vacuum without clamping or contacting the side of the workpiece which is undergoing processing.

It is a further object of this invention to control the amount of gas which leaks into the vacuum chamber from the space between the workpiece and the surface on which it is supported, such that the leakage of gas does not adversely affect the processing of the wafer.

It is a further object of this invention to minimize and control sources of damage and contamination which have tended to accompany prior techniques of thermoregulation.

In accordance with the present invention, the temperature of a workpiece, such as a wafer, is controlled in a vacuum chamber by fixing the wafer on a flat platen and introducing a heat transfer medium in a peripheral region of the wafer between the wafer and platen . The wafer is urged against the platen with a low contact pressure distributed over its surface, and the opposed faces of the wafer and of the platen are both smooth and flat so that the heat transfer medium fills a space essentially defined by surface roughness of the contacting objects. The roughness is kept low enough that the heat transfer rate is high and the wafer is conductively cooled to the temperature of the platen. Centrifugal, magnetic (for ferromagnetic workpieces) or electrostatic clamping (for resistive workpieces), are employed to achieve an even force distribution over the whole surface of the workpiece without covering any portion of the face. A vacuum channel formed in the surface of the platen may scavenge the heat transfer fluid by differential pumping to keep the amount of residual fluid

leaking out from under the wafer from degrading chamber pressure. Preferably, a flatness is maintained of better than 10-20 microns across the workpiece and the platen surface, and a surface roughness kept below approximately .8 microns so that when clamped together the workpiece and platen provide a fluid thermal contact space with leakage to the vacuum chamber at a level substantially below the static load from all other process sources. An electrostatic clamp includes a plurality of long, thin electrode regions which are activated in a sequence different from their spatial ordering to provide a non-motoring but dynamic pattern of clamping forces.

Brief Description of the Drawings

These and other features of the invention will be understood from the description below, illustrated by exemplary figures, wherein:

FIG. 1. shows a prior art cooling mechanism;

FIG. 2 shows another prior art cooling mechanism;

FIG. 3 shows another prior art cooling mechanism;

FIGS. 4 and 4a show a basic embodiment of the present invention and illustrate the distribution of pressure therein;

FIG. 4B shows another embodiment;

FIG. 5 illustrates gas pressure as a function of molecular weight of the gas species used;

FIG. 6 illustrates mean free path of a gas molecule as a function of molecular weight of the gas;

FIG. 7 shows a differential pumping embodiment of the present invention;

FIG. 8a shows a top view of an electrostatic clamping embodiment of the present invention;

FIGS. 8b and 8c show details of construction of the electrostatic clamp of FIG. 8a;

FIG. 9. shows electrical waveforms used in a preferred embodiment of the electrostatically clamped apparatus, and the resultant force developed; and

FIG. 10 shows an embodiment of the present invention in which centrifugal force clamps the workpiece to a fluid heated or cooled mounting member.

Detailed Description

The patents of King and Holden mentioned above describe apparatus and methods for gas-assisted heating and cooling of workpieces undergoing treatment in vacuum using mechanical clamps which make contact with the front (processed) side of the workpiece, and which use peripheral seals to confine a cooling gas. Others have suggested that fluid cooling, with some leakage is more effective than metal-to-metal contact, for some applications, but have not addressed the complex trade-off between such factors as clamp pressure, gas species, leakage and cooling rates. The invention is best understood following a detailed consideration of the overall approach shown in the aforesaid two patents.

In one prior art construction shown in FIG. 1, a semiconductor wafer 2 is clamped with a ring clamp 30 against a cooled flat support member 23. An O-ring 20 set in the surface of the support 23 directly opposite the ring clamp provides a seal to confine gas which is introduced under pressure through an orifice 22 into the space between the wafer and the support member. This technology has been used in ion implantation, but has disadvantages which include applying stress to the wafer, and generation of particles on the front side of the wafer, loss of usable area of semiconductor wafer material due to masking by the clamp ring, sputtering of contaminants from the clamp ring onto the wafer, and a less than optimal cooling effectiveness, since the cooling which can be obtained is reduced due to bowing of the wafer under the influences of localized clamping on the front and uniform gas pressure on the rear surfaces.

In another construction of the prior art shown in FIG. 2, the tendency of the cooling gas to cause the wafer to bow is recognized and addressed. In this construction, a platen 36 is gently domed so that the action of clamping the wafer 2 at its periphery with ring 42 against the platen 36 causes the wafer to gently bend over the platen and to bear against the platen with an approximately uniform degree of contact prior to introduction of gas under pressure through channel 37. The domed shape of the platen prevents the separation of wafer and platen, at moderate gas pressures. As discussed in the cited patents, too great a separation is known to reduce the level of obtainable thermal transfer, so this construction attains better cooling characteristics. Disadvantages of this approach, however, include the variation of the angle of incidence of the ion beam over the wafer surface due to the wafer curvature, which

as discussed above, lead to undesirable process variations. Those include planar channeling, and breakage of wafers with pre-existing defects, as well as the aforementioned general disadvantages of front-surface clamping.

FIG. 3 shows a variation of the prior art approach shown in FIG. 1, with the stage, clamping, and cooling mechanisms integrated into a wafer holding assembly. In this embodiment, the wafer 2 rests vertically against a heat sink member 119 that is actively cooled by a flow of fluid through inlet and outlet tubes 128, 129. The front face of the member 119 has a central flat recessed floor 125, and a plurality of small clip assemblies 103, which each are moved by a machine actuated mechanism 104, hold the wafer 2 down against a peripheral lip of the heat sink, so that the wafer is close to, but not touching the face 125. A central gas inlet feeds argon at 100-1000 microns pressure into the space between the wafer and heat sink to raise the pressure and increase the rate of heat transfer. When used for heating a wafer the gas may be heated. When used for cooling, the gas pressure is ten or more times greater than the residual gas pressure in the chamber, and a certain amount of the heat transfer gas leaks out past edges of the wafer to maintain the normal ten micron chamber pressure of a sputtering chamber. The heat sink is mounted on a backing plate 120 that seals against the vacuum chamber wall 102 via an 0-ring seal 121, and when not in its operative position, the opening in wall 102 is covered by a pressure plate 105 and seal ring 101. Both the gas introduction passage 126 and the fluid heat exchange passages 128, 129 for the heat exchange plate pass through the backing plate 120. While the edge clips 103 reduce somewhat the wasted wafer area given over to the clamp ring in the construction of Figure 1, the problems inherent in that construction remain.

The present invention departs from these prior art approaches in providing gas under pressure as a thermal transfer medium into a space of random variations formed between two flat and mutually contacting surfaces while the workpiece is urged with a force distributed over its entire surface against a platen over a broad contact area. Gas is introduced along a peripheral line contour to provide substantially uniform thermal conduction. Typically, the workpiece is a thin flat wafer, and the workpieces are heated or cooled by mounting each workpiece to a very flat platen with substantially uniform pressure, and by introducing the gas between the wafer and the platen. The platen is made as flat as practical, preferably better than +/- 0.0005", with the exception of holes and grooves for the transfer medium as described further below, and is polished smooth.

Advantageously, no attempt is made to create a hermetic seal in any localized region between the wafer and the platen which would require local pressures many orders of magnitude greater than the mean pressure. Rather, both the platen and the workpiece are made sufficiently flat to come into uniform contact or substantially uniformly contacting

proximity, and are made smooth with a microscopic roughness preferably not exceeding 32 micro inches. The gas occupies the microscopic valley spaces in the surfaces of the platen and the workpiece. A small rate of leakage of gas from the edges of the platen is matched by a constant flow of gas introduced by way of a groove or ring of holes in the platen surface, running along a contour fairly close to the edge of the wafer, into the region between the workpiece and the platen. The area of gas introduction forms an isobaric boundary around the center of the wafer space, which otherwise has no gas outlet. This assures that, despite the irregular shape and very narrow dimension of the space occupied by the transfer medium, the gas remains distributed uniformly under the workpiece, in a wafer-to-platen gap that is smaller than the mean free path length of the gas. Conductive heat transfer is therefore maximized.

Rather than the prior art clamping forces localized at the periphery, in accordance with this invention the pressure applied between the workpiece and the platen is low and is substantially uniform over the full surface of the platen. Suitable clamping forces are applied by gravity (for sufficiently dense workpieces and/or low enough gas cooling pressure), centripetal acceleration, magnetic clamping (for ferromagnetic workpieces) or electrostatic clamping (for moderately conductive workpieces such as silicon wafers).

FIG. 4 shows this construction. A flat thin workpiece 2 is placed in high vacuum upon a flat platen 201, through which a liquid such as water is passed in channels 204. The liquid can be heated, cooled or maintained at a reference temperature as required for the process and substances involved. A gas is introduced at a flow controlled by flow controller 205 at a rate of approximately 0.25 sccm into a conduit or channel that feeds via a ring or circular groove 203 into the interface between the workpiece and the platen. This groove or ring of holes 203 is referred to below as the gas introduction ring. Notably, while in prior art constructions the pressure of the cooling gas is controlled, in accordance with this invention the mass flow is controlled. This important difference produces effects in several ways described more fully below which, in conjunction with the lack of a peripheral seal and the use of highly flat surfaces, assure that both the pressure and the nominal thermal transfer gap spacing are kept quite low, while obtaining high rate of heat transfer.

When a wafer is partially covered with a photoresist mask undergoing ion implantation, the photoresist alone can be a source of several standard cubic centimeters per minute (sccm) of hydrogen gas liberated by the action of the ion beam on the organic photoresist. Thus the leakage by a wafer cooling system of a small fraction of one sccm of gas, possibly hydrogen, may not significantly affect the implantation process, particularly if the reduction in temperature of the wafer achieved by such cooling has a compensating negative effect upon the volume of hydrogen being liberated by the resist. Thus, the gas

cooling system may safely introduce a certain amount of gas, especially if, as described above, the amount of cooling gas is less than the amount by which the temperature change reduces outgassing. Based on this realization, applicant has determined a structure for a heat exchange platen to operate with such a defined flow of gas leakage.

If the surfaces were perfectly flat, then such a regulated flow of gas would theoretically cause the workpiece to lift off the platen to a distance just sufficient to allow the flow of gas to escape at the edges of the platen. However, in accordance with applicant's practice, the surface of a semiconductor wafer has a roughness within conventionally attained finishing standards of, for example, twelve micro inches r.m.s., and defects in flatness of up to several ten thousandths of an inch are allowed to occur. Applicant advantageously utilizes these surface variations to maintain firm contact between the workpiece and the platen with additional conductive heat transfer effected by a gas at low gas pressure and flow rates matched to the irregular interstitial heat transfer space defined by the foregoing surface finish features, as discussed further below.

FIG. 4a shows a graph of gas pressure within the wafer/platen interstitial space as a function of position from one side of the wafer to the other. Inside the gas introduction contour, ring 203, the pressure of gas reaches a steady state shortly after the gas flow commences. In practice, this pump-up interval is found to be one second or less.

If the gas were simply to be introduced through a hole at the center of the wafer/platen assembly, as is the case in some existing commercial equipment (for example, via the elements depicted in the above described prior art as element 22 in FIG. 1, or 126 in FIG. 3), the pressure profile beneath the wafer in the absence of the mechanical edge clamping and elastomer sealing shown would be high at the center relative to the edges This would introduce non-uniform heat transfer, and the rate of gas leakage would also have to be much higher to maintain suitable pressure at the edge. The introduction of the gas according to this invention in a contour close to the edge of the platen allows the pressure to come to static equilibrium over an interior region covering the greater part of the space between the wafer and the workpiece, as shown by the pressure profile in FIG. 4a, without requiring such high pressure to achieve effective heat conduction. Applicant achieves this without use of clamp rings or seals, and is therefore able to avoid pressure-distortion of the wafer.

In an alternative embodiment shown in Figure 4B, the platen may be provided with a gas introduction hole 203a at its center, as in Figure 1, but with this hole linked by one or more grooves 203b, 203c which extend to an outer groove 203 occupying a peripheral contour close to the edge of the platen. The linking groove or grooves 203b, 203c may be located below the face of the platen as illustrated, or may consist of narrow channels in the

face itself. In either case, they serve as pressure shunts to uniformize the pressure distribution under the workpiece, again producing a substantially constant pressure distribution as shown in Figure 4A and allowing operation at a minimal heat transfer fluid pressure simultaneously with minimal distortion of the thin workpiece, and effective thermal regulation is achieved without excessive leakage of fluid into the process chamber.

Operation of the invention may be understood from the following brief discussion.

The region outside the gas introduction ring 203 bounded by the flat wafer and the flat platen has a small conductance of

$$C = 2\pi r g^2 c/3l \qquad (1)$$

where g^2 is the mean square gap between the wafer and the platen, l is the distance from the gas introduction ring 203 to the outer limit of the gas-cooled region, and r is the radius of the gas introduction ring. Provided the surfaces are sufficiently flat and parallel, the leakage is low enough to eliminate the requirement for seals.

The cooling rate in this region can be shown to be

$$Q/A = 0.33 a \gamma k n c (T_W - T_p) \qquad (2)$$

in MKSA units, where a is the accommodation coefficient of the gas on the surfaces, γk is the heat capacity per molecule per degree, k is Boltzmann's constant, n is the gas density, c is the mean gas velocity, T_W is the wafer temperature and T_p is the platen temperature. The rate at which gas molecules cross unit area normal to the platen surface transporting energy, which is given by 0.33 nc and thus appears in equation (1), can be evaluated by equating the rate of gas introduction, F, to the rate of gas loss between the workpiece and the platen through the annular space outside the gas introduction ring. Since $F = PC$, where P is the gas pressure, and $P = nkT$, nc can be evaluated to be:

$$nc = 3Fl/(2\pi r g^2 kT) \qquad (3)$$

where T is the mean temperature.

The rate of cooling is proportional to the gas flow, proportional to the distance from the gas introduction ring 3 to the platen edge, and inversely proportional to the mean square gap. The mean square gap is determined by the surface finish and flatness of the workpiece

and of the platen. Interestingly, in these equations the choice of gas only enters through the effect of γ.

In this discussion two implicit assumptions have been made: that the gas mean free path is greater than the r.m.s. gap between the wafer and the platen so as to maximize the heat transfer rate, and that the gas pressure is less than the time averaged clamping pressure between the workpiece and the platen, so that the gap doesn't change with pressure. The gas pressure which results for a given flow rate depends upon n, which is inversely proportional to c, where

$$c^2 = 2kT/M \tag{4}$$

and M is the molecular weight of the gas. Thus, for a given flow rate, a lighter gas develops a lower pressure behind the wafer. The dependence of pressure on an atomic number A is plotted in FIG. 5. To minimize the pressure required, hydrogen is applicant's preferred heat transfer gas.

The mean free path also depends upon the atomic/molecular number A of the gas selected, as shown in FIG. 6. Both pressure and mean free path may also be affected by chemical properties of the gas not discussed further here. The importance of the mean free path is that if it is less than the gap such that a significant number of gas-gas collisions occur between the workpiece and the platen, then the cooling rate is considerably reduced. A discussion of the relationship between the gap and mean free path in their effect in heat transfer rate may be found in the two patents noted above.

It should be noted that the gas heat transfer medium introduced at the periphery of the wafer need not enter via a full circular port. Instead, a plurality of discrete inlet ports 203a, 203b. . . may be distributed along a closed contour in a peripheral region of the platen. In that case, diffusive flow of the gas operates to smooth the overall distribution profile. In each case, the result is a substantially constant and stationary gas profile in the central region, and a small but balanced flow of gas with a decreasing pressure profile across the thin peripheral band region outside of the gas introduction contour.

Note that the pressure within the gas introduction ring is uniform, and, in the absence of localized clamp forces, there are no deflections caused by differential pressures or pinned edges, and the workpiece therefore remains flat. The rate of cooling does not extend uniformly to the edge of the wafer beyond the gas introduction ring, because the pressure drops smoothly from the gas introduction ring to the platen edge, as shown in FIG. 4A. However, consequences of this pressure drop-off effect may be minimized by requiring that

the length l between the gas introduction ring and platen edge be small. In accordance with equation (1), to decrease the distance in this fashion increases the gas flow required to obtain a given cooling rate, and therefore undesirably raises the pressure in the vacuum chamber.

However, despite the greater flow with small l, applicant has determined that it is not necessary to use a localized seal at the edge of the wafer, provided that all surfaces are flat and polished to limits suitable to make the rate of gas leakage low. For example, for an effective r.m.s. roughness of a 200mm dia silicon wafer of 20 microns, and with a gas supply rate of 0.25 s.c.c.m., and $l = 33$mm, then the cooling rate for a gas with γ=1.5 is 1.895 watts per square centimeter for a temperature difference of eighty degrees centigrade between the wafer and platen.

In a preferred embodiment of the present invention, illustrated in FIG. 7, leakage of gas into the high vacuum chamber is further reduced to a small fraction of the rate at which the gas is supplied by the flow controller 205, by providing a gas scavenger assembly along the diffusion path between the inlet orifice and the vacuum chamber. As shown in FIG. 7, platen 201 is situated in a high vacuum chamber (not shown) and a workpiece (not shown for clarity) is placed upon the flat surface 209 of the platen. Gas is introduced through the first annular groove 203, and a second annular groove 207 (or ring of holes) located radially outward from groove 203 surrounds the inlet. Preferably the second groove is located approximately one and a half millimeters inwardly from the outer edge of the platen 201. The second groove 207 connects via a passage to a mechanical vacuum pump 206 that provides differential pumping, i.e. pumping to a vacuum level higher than the manifold pressure of inlet 203, and close to or even higher than the vacuum level in the surrounding chamber. As the cooling or heating gas leaks radially outward in the interstitial space, it enters this groove, and the greater part of it is removed from the system by pump 206 without traveling further outward or leaking into the high vacuum chamber. Thus, the cooling gas does not compromise the high vacuum environment in which the wafer is processed. One or more large conduits 207a lead from the scavenging groove 207 to the pump 206, making the conductance of the path from groove 207 to pump 206 substantially greater than the conductance from groove 207 into the vacuum chamber, thus favoring scavenging of gas along the out-diffusion route.

Another preferred embodiment 250 is illustrated in FIGS. 8a, 8b and 8c. The platen of this system includes an electrostatic clamp to apply pressure which holds the wafer workpiece to the platen. This method works well for conductive workpieces. The technique is similar to that described by J. Ballou, K. Carson, W. Frutiger, J. Greco and R. Kaim in Proceedings of the Ion Implantation Technology Conference IIT '94, Catania, Italy.

As best seen in the top view, FIG. 8a, the workpiece-contacting (front) surface of the platen 250 includes a flat lapped and polished sheet of a dielectric material, 52, composed, for example, of aluminum oxide, with a thickness preferably between about (0.15)-(0.2) millimeters, and which forms a plurality of operative charging regions defined by a metallized electrode pattern deposited on its back surface. The metallized back pattern provides a set of plural electrodes 51 of approximately equal area, preferably differing by under one-quarter of one percent. In the illustrated embodiment, four electrodes 51a, 51b, 51c, 51d of spiral shape, each approximately ten millimeters in width and less than one-quarter millimeter thick, and each electrically separated from the others by a small in-plane gap of up to several millimeters or more, define a set of closely spaced charging regions that collectively cover the front surface of the platen. Advantageously, the electrodes are long and thin, and each covers a path along a dispersed region of the circular wafer that is interdigitated with the other electrode regions. The spiral form, however, is not itself critical, but merely represents one option for forming such a regular electrode pattern, and deviations from a regular plane spiral shape may also be made to accommodate electrode connections or when convenient for other reasons. In general, however, the regular electrode pattern is preferably formed of regions that are not large isolated blocks, and do not correspond to nodal regions of lower order wafer resonances, so that the necessary fluctuations in force caused by the clamp drive signals cannot induce large mechanical vibrations. In FIG. 8a, the flat conductive workpiece 2 of the polished dielectric layer 52 is omitted for clarity, and electrodes 51 are shown visible through the dielectric layer 52, which is typically transparent or translucent.

FIG. 8b shows a vertical section through the platen 250, with a wafer 2 of radius R lying flat on the platen surface so that it covers the gas introduction inlet 203 positioned at radial distance of (R-1), from the center and also covers the gas scavenging groove 207, lying at a distance δ inward from the wafer edge. The view of FIG. 8c is an enlargement of part of the cross section to more clearly illustrate the layered construction. Workpiece 2 is shown. Its plate-contacting surface 2a has micro-roughness as described above, which forms the roughened ceiling of a crack-like opening 2b allowing the passage of gas, while the alumina dielectric layer 52 has a generally smoother and flatter surface 52a, which may, for example, be optically polished and which acts as a floor of the gas-filled space. Electrodes 51 are sandwiched between the alumina dielectric layer 52 and another dielectric layer 53, which may be a hard inorganic material like layer 52 or may be an organic polymer and which also effects a bond to the underlying body of platen 250.

The entire top surface of this assembly is preferably lapped to a flatness of (0.0125) millimeters or better, and polished to a finish which is preferably better than about eight micro inches, i.e., (0.2) micrometers r.m.s. The dielectric layer 52 is bounded by the groove

207, and the upper face of the outer wall of this groove is also lapped and polished, forming part of the same flat plane as the top of layer 52.

To operate the illustrated surface construction of dielectric and electrode regions to electrostatically clamp a wafer, alternating voltages with a trapezoidal waveform are applied to the electrodes 51a, 51b, 51c, and 51d at a frequency of about thirty to sixty Hz. FIG. 9 indicates a set of signal waveforms and preferred phase relationships for these clamp operating signals. Each signal is a periodically repeating trapezoidal wave shape that ramps up and down between an upper potential *u* and a lower potential *l*, and each is identical to the others except for phase, the first and fourth being of opposite phase, as are the second and third signals, while the first and second signals are shifted by a quarter period with respect to each other. The wafer 2 lying on top of layer 52 serves as a common electrode for charging all four of the dielectric regions over the spiral electrode arms 51a-51d, and the applied voltages generate an electric field of about 5 MV/m or more between the electrodes and the surface of the wafer.

The instantaneous clamping pressure P above one electrode is approximately given by:

$$P = \frac{-\varepsilon_0 \varepsilon^2 V^2}{2t^2} \qquad (5)$$

where ε_0 is the permitivity of free space, ε is the dielectric constant of the dielectric material (which is about 9 to 10 for aluminum oxide), V is the applied voltage, and t is the thickness of the dielectric, which as noted above, is of a dimension much greater than the surface roughness of the dielectric or of the back surface of the workpiece being clamped, and is also much greater than the large-scale variation from flatness across each of these surfaces. The net clamping force on the wafer as a whole, shown in the fifth line of FIG.9, dips during the voltage switching intervals. To prevent significant vibration, the width of the electrodes is small, preferably under ten millimeters. This reduces the amplitude of any vibration, and raises the resonant frequencies of any vibrational modes which might be excited in the wafer or platen, ensuring that the vibration induced by the spatially- and time-varying clamping forces is far removed from any mechanical resonance of the platen or workpiece.

In the preferred embodiment four electrodes shaped in a spiral pattern are used, and a four-phase a.c. trapezoidal waveform is applied. The electrodes are arranged in pairs that receive actuating signals that are exactly out of phase, with one signal ramping up while the other signal of a pair is ramping down. Furthermore, while the electrode of one region of dielectric is experiencing a changing potential, another region is clamped with a fixed voltage

at maximum magnitude so the dips occur in isolated regions. The invention also contemplates clamping with larger even numbers of electrodes and phases. By providing an even number of phases, applicant ensures that the potential of the wafer is unaffected by the application of the electrostatic clamping signal waveforms. There is thus no need to ground the wafer, since the total current to the wafer at any time is null. The phase sequence is applied to non-sequential electrodes, for example 1-2-4-3 or 1-3-4-2; this removes any "motoring" component from the forces imparted to the wafer and avoids generating traveling waves which would have a tendency to move the wafer in a single direction.

The foregoing constructions rely on extreme closeness between the wafer and the platen to assure efficient cooling and to a lesser extent effective clamping. However, particles do arise in the processing environment, and in the event that a particle lands on the platen and accidentally separates the workpiece from the platen, certain consequences will occur from resulting changes in surface spacing. First, thermal transfer will be greatly reduced according to equations (2) and (3), since the distance from the workpiece to the platen is increased. The differential pumping may also become ineffective to maintain the desired pressure under the wafer, since with a controlled gas flow, the flow into the vacuum chamber can rise to no higher than the controlled gas flow rate, and with excessive leakage, this rate may be inadequate to maintain the desired level of thermal transfer. Furthermore, the current flowing to the electrodes of the electrostatic clamp will be reduced when the wafer is not in intimate contact with the dielectric, since the introduction of an additional air gap between the wafer and the back electrodes greatly decreases capacitance. Applicant exploits this latter feature by monitoring clamp current for example, with threshold detectors. The threshold crossing may trigger an alarm. That is, automatic measurement of this current immediately indicates the presence of a particle and/or incorrect placement of the workpiece.

By contrast, in prior art systems, the presence of debris on the platen might cause a mechanical clamp to break the wafer, or could grind the particle into the surface of the platen causing longer lasting damage, and such a problem would generally be undetected until after a number of wafers had been processed and the processing had resulted in observable defects. Also, in contrast to the harmless consequences on applicant's gas flow, in a system even without a mechanical clamp but in which the gas pressure rather than its flow regulated, then rather than being self-limiting, the resultant leakage into the high vacuum chamber could be a catastrophic event that harms process equipment and overloads high vacuum pumps.

In yet another embodiment of a system 400 of the present invention shown in FIG. 10, a set of platens 401 similar to those shown in FIG. 4 or FIG. 7 are mounted to a spinning disk or drum 55 in a surface region that is inclined with respect to the plane of rotation such that centripetal force urges each wafer against the face of the platen as the wafers are rotated

past a treatment station. Analogously, a set of radial arms (as shown in Robinson et al., U.S. Patent No. 4,733,091) may be used to impart such a centrifugal clamping mechanism. By tilting the platens so that the wafer-contacting surfaces face slightly towards the axis of rotation, a component of centripetal force is developed, which acts to press the workpieces onto the platens while holding them in an orientation for processing. The clamping pressure is given by

$$P = \rho t_w r \omega^2 \sin\alpha \qquad (6)$$

where ρ is the density of the workpiece, t_w is its thickness (which is assumed uniform), r is the mean radius of revolution, ω is the angular velocity, and α is the angle between a radius and the cooling/heating surface. An angle of five to ten degrees is sufficient at reasonable drum rotation rates to secure the wafers flat enough for conductive gas thermal transfer cooling in accordance with this invention.

It will be understood that the invention disclosed herein, although mainly described as applied to circular semiconductor wafers, is readily adapted to other shapes and other materials, e.g., to square or rectangular flat substrates such as sensors, flat panel displays, and other shapes or articles requiring vacuum treatment. In such cases, the peripheral gas introduction channel or ring, and the scavenging or differential pumping ring, if one is used, will in general each lie on a non-circular contour. The principal of operation is in other respects similar, and for non-circular substrates the advantages of distributed clamp force and uniform heat transfer characteristics may be expected to offer even more significant improvements over presently available workholders and thermal control systems. The invention being thus disclosed and explained, other variations and modifications will occur to those skilled in the art, and are intended to be within the scope of the invention per defined by the claims appended hereto.

What is claimed is:

Claims:

1. Apparatus for thermal control of a flat workpiece during processing in a vacuum chamber comprising:

a platen including a flat smooth platen surface for supporting the workpiece in a processing position with a surface of the workpiece exposed to said vacuum chamber, said platen surface having a central region and a peripheral region,

means for clamping the workpiece to the platen surface with substantially uniform pressure across its surface,

means for introducing a controlled flow of gas as a heat conducting medium at the platen surface in said peripheral region to provide thermal conduction between the platen and the workpiece such that the gas fills a space in said central region essentially defined by surface roughness of said platen surface and the workpiece at a steady state, and

means for controlling the temperature of the platen so that the gas effectively and uniformly conducts heat from the workpiece to the platen over said central region.

2. Apparatus of claim 1 wherein the clamping means includes electrostatic clamping means for securing the workpiece to the platen surface by electrostatic force.

3. Apparatus of claim 1 further comprising gas scavenging means in said peripheral region of the platen surface located radially outwardly of the introducing means for scavenging gas introduced by the introducing means to reduce leakage of said flow of gas past an edge of the platen into the vacuum chamber.

4. Apparatus for holding a flat-backed workpiece during processing in a vacuum chamber comprising:

a multi-layer platen structure including:

a first dielectric layer of hard material having a flat surface to contact the back of the workpiece,

a patterned thin metal layer including at least four electrodes of approximately equal area,

a second dielectric layer,

a rigid base supporting said layers in sequence,

means for controlling temperature of said rigid base,

at least a first gas introduction opening in the workpiece-contacting face of said platen structure for introducing gas between the platen and a workpiece resting thereon along a contour about a central region of said platen

clamping power supply and control means for applying to each of said electrodes alternating voltages sufficient to develop an electric field of at least 2 MV/m in the first dielectric layer, and

means for introducing a controlled flow of gas through said gas introduction opening into the region between the workpiece and the platen, the electric field maintaining the workpiece in contact with said first dielectric layer of hard material such that surface roughness of the workpiece forms an interstitial space of dimension less than a mean free path of gas introduced in said region so that gas introduced via said opening effects enhanced conductive thermal transfer between the workpiece and the platen.

5. Apparatus of claim 4 further comprising a gas evacuation opening in a workpiece contacting face of said platen structure between said gas introduction opening and the edge of said platen, said gas evacuation opening being connected to differentially pump and thereby reduce leakage of said flow of gas into said vacuum chamber.

6. Apparatus of claim 4 wherein said alternating voltages have a generally trapezoidal waveform.

7. Apparatus of claim 4 wherein said alternating voltages are spaced equally in phase.

8. Apparatus of claim 4 wherein said electrodes extend next to each other in a sequence, and said alternating voltages are applied to said electrodes in a non-sequential order.

9. Apparatus of claim 4 wherein said first and second dielectric layers are each thermally conductive.

10. In a method of treating a flat workpiece in a vacuum chamber that includes the steps of positioning the workpiece on a flat support plate at a treating station within said vacuum

chamber, and introducing gas between the workpiece and the support plate to conduct heat between the workpiece and the support plate, the additional steps of:

providing a source of pressure distributed uniformly over the workpiece to hold the workpiece against the support plate, and

introducing a controlled flow of said gas along a contour radially inward from the edge of the support plate such that the gas fills an interstitial space between the workpiece and the support plate having a gap less than mean free path length of said gas and defines a heat conduction region of constant pressure in a central portion of said workpiece within said contour.

11. The method of claim 10 further comprising the step of differentially pumping gas from between the workpiece and the plate at the periphery of said support plate to reduce flow of gas entering the vacuum chamber.

12. The method of claim 10 wherein the step of providing pressure is effected by electrostatically clamping the workpiece to the support plate.

13. The method of claim 10 wherein the step of providing pressure is effected by providing centripetal force to urge the support plate and the workpiece together, said support plate being mounted on a rotating assembly.

14. The method of claim 10 wherein the step of providing pressure is effected by arranging that gravity presses the workpiece against the support plate.

15. In a method of electrostatic clamping for providing substantially uniform pressure between a flat thin conductive workpiece and a mounting member, said mounting member comprising at least a top layer composed of flat dielectric, a second layer of metal divided into a pattern of at least four electrodes of substantially equal area, and a third layer of dielectric , the additional steps of:

arranging that the electrodes extend next to each other in a sequence,

providing alternating voltage sources of equal amplitude and of equally spaced phase connected to each of said electrodes,

connecting said voltage sources in non-sequential order to the electrodes to introduce a dynamic and non-motoring pattern of electrostatic clamp forces for clamping the workpiece to the mounting member.

16. The method of claim 15 wherein the step of arranging includes arranging that said electrodes are patterned electrodes of generally spiral form, thereby reducing magnitude of circulating currents and of vibrations induced in the workpiece by said alternating voltages.

17. The method of claim 15 further comprising the step of monitoring current of said connected voltage sources to detect presence of the workpiece on said mounting member and determine its degree of contact therewith.

18. A method of thermally regulating a workpiece on a platen in a vacuum chamber, such method comprising the steps of

arranging that the workpiece and platen are urged into contact with each other along respective flat surfaces having a root means square surface roughness under several micrometers

arranging that the platen is thermally regulated, and

introducing a fluid medium in a peripheral contour so that it permeates into an interstitial space consisting of surface roughness between said respective flat surfaces to form an isobaric central region of fluid filling said surface roughness so that the fluid conducts heat across a gap of under several micrometers between the workpiece and the thermally regulated platen to conduct heat uniformly from said workpiece with enhanced efficiency.

19. The method of claim 18, further comprising the step of providing a low pressure scavenging port surrounding said peripheral contour to reduce leakage of the fluid medium into the vacuum chamber.

20. The method of claim 18, wherein the step of introducing a fluid medium is done by introducing a constant mass flow of fluid to said peripheral contour.

21. Apparatus for clamping a flat thin conductive workpiece to a mounting member, the mounting member having at least a flat top layer of dielectric material, a conductive sublayer divided into a pattern of at least four electrodes, and an underneath layer of dielectric material wherein the electrodes are all of substantially equal area and extend next to each other in a sequence, and further comprising activation means for applying a plurality of voltage sources

having signals of substantially equal amplitude and uniformly spaced phase to said electrodes in a non-sequential order to produce a non-motoring clamp force, and means for monitoring said electrodes to determine degree of contact when a workpiece is present on said mounting member.

22. In a method of electrostatic clamping for providing substantially uniform pressure between a flat thin conductive workpiece and a mounting member, said mounting member comprising at least a top layer composed of flat dielectric, a second layer of metal divided into a pattern of at least four electrodes of substantially equal area, and a third layer of dielectric, the additional steps of:

arranging the electrodes extend next to each other in a sequence,

providing alternating voltage sources of equal amplitude and equally spaced phase connected to each of said electrodes,

connecting said voltage sources to the electrodes to introduce electrostatic clamp forces for clamping the workpiece to the mounting member

wherein the step of arranging includes arranging that said electrodes are patterned electrodes of generally spiral form, thereby reducing magnitude of circulating currents and of vibrations induced in the workpiece by said alternating voltages.

23. In a method of electrostatic clamping for providing substantially uniform pressure between a flat thin conductive workpiece and a mounting member, said mounting member comprising at least a top layer composed of flat dielectric, a second layer of metal divided into a pattern of at least four electrodes of substantially equal area, and a third layer of dielectric, the additional steps of:

arranging the electrodes extend next to each other in a sequence,

providing alternating voltage sources of equal amplitude and equally spaced phase connected to each of said electrodes,

connecting said voltage sources to the electrodes to introduce electrostatic clamp forces for clamping the workpiece to the mounting member

said electrodes extending in pairs along turning paths which are closely spaced to effectively limit magnitude of circulating currents and vibration induced in the workpiece.

24. In a method of electrostatic clamping for providing substantially uniform pressure between a flat thin conductive workpiece and a mounting member, said mounting member comprising at least a top layer composed of flat dielectric, a second layer of metal divided into a pattern of at least four electrodes of substantially equal area, and third layer of dielectric, the additional steps of:

arranging that the electrodes extend next to each other in a sequence,

providing alternating voltage sources of equal amplitude and of equally spaced phase connected to each of said electrodes

connecting said voltage sources to the electrodes to introduce electrostatic clamp forces for clamping the workpiece to the mounting member

further comprising the step of monitoring current of said connected voltage sources when the workpiece is on said mounting member to determine its degree of contact.

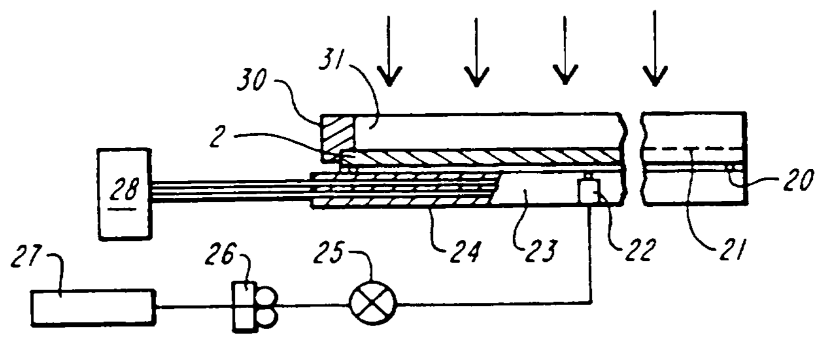


FIG. 1
(PRIOR ART)

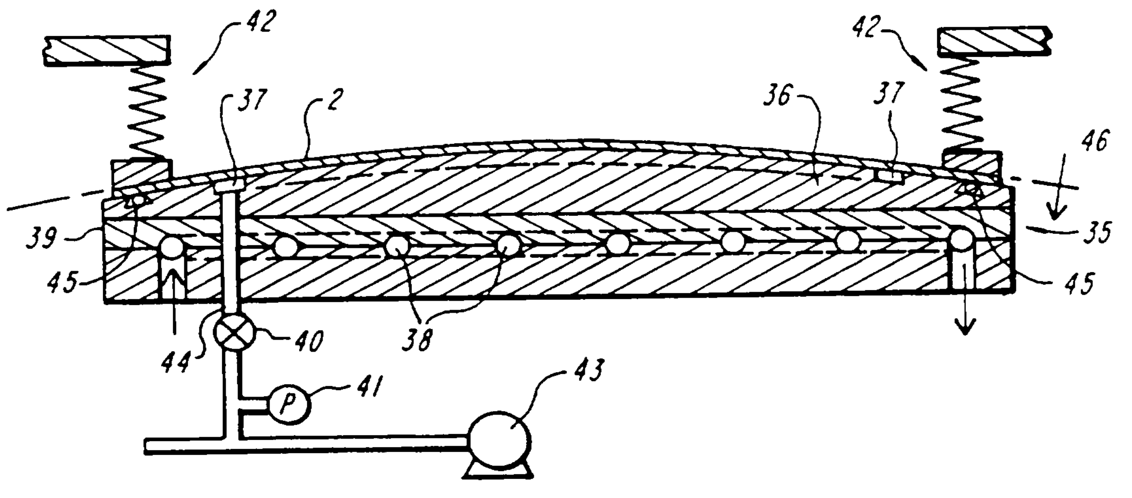


FIG. 2
(PRIOR ART)

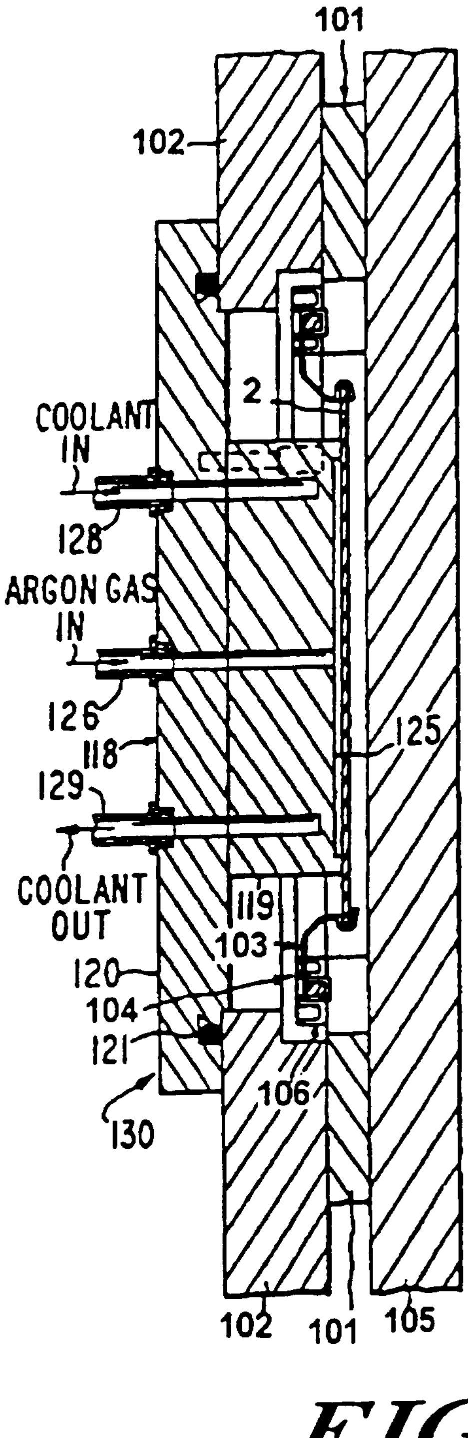


FIG. 3
(PRIOR ART)

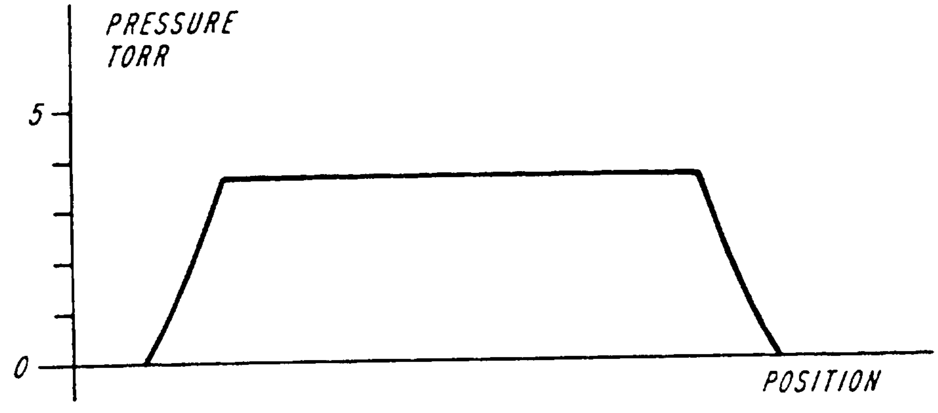


FIG. 4A

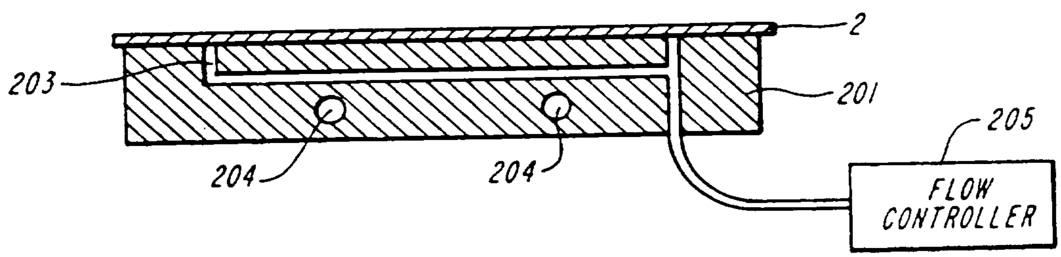


FIG. 4

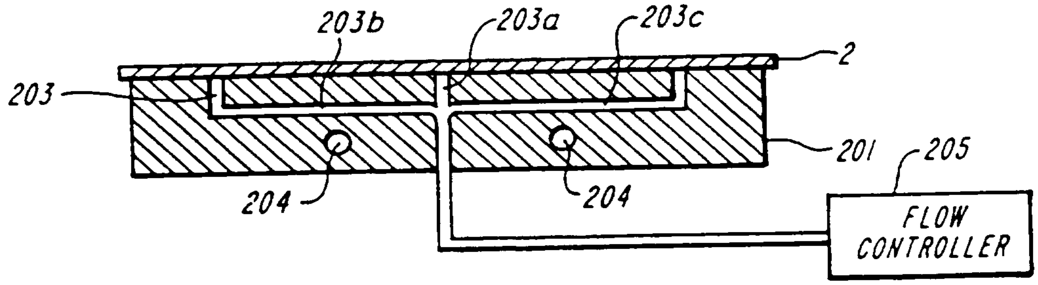


FIG. 4B

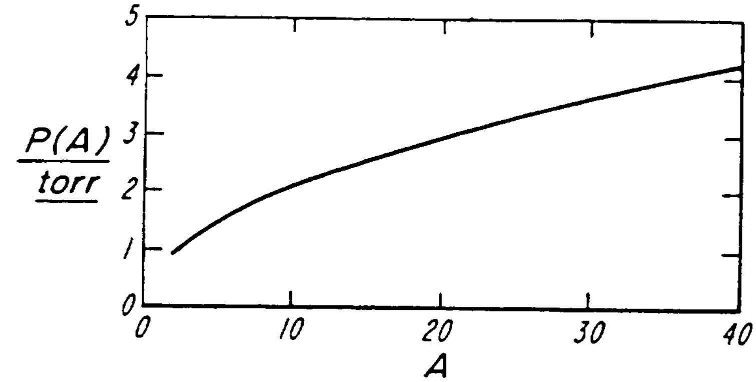


FIG. 5

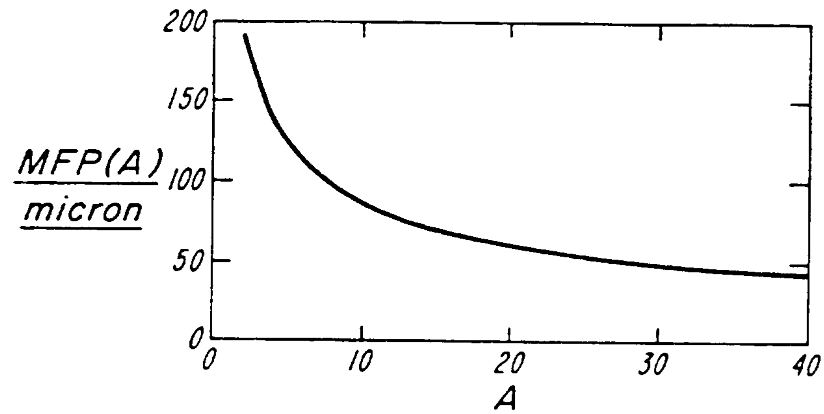


FIG. 6

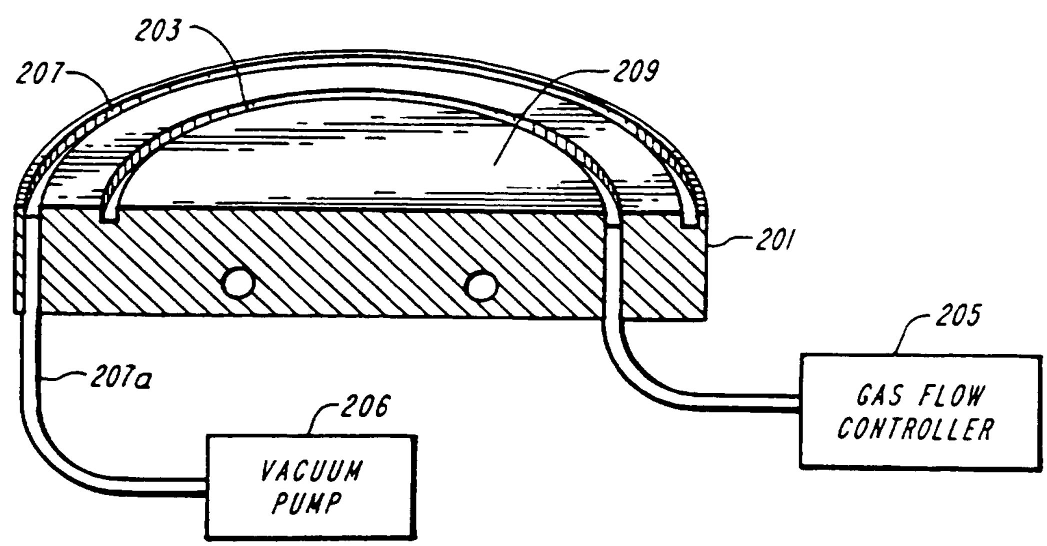


FIG. 7

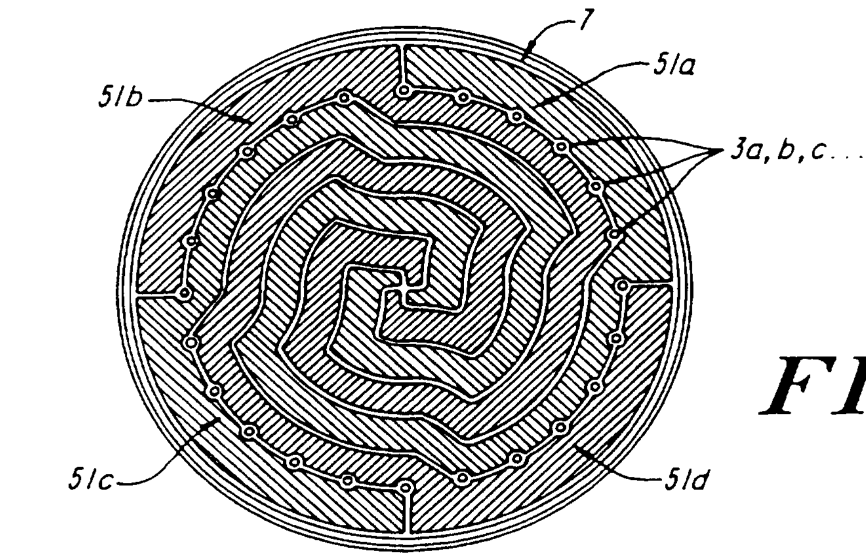


FIG. 8A

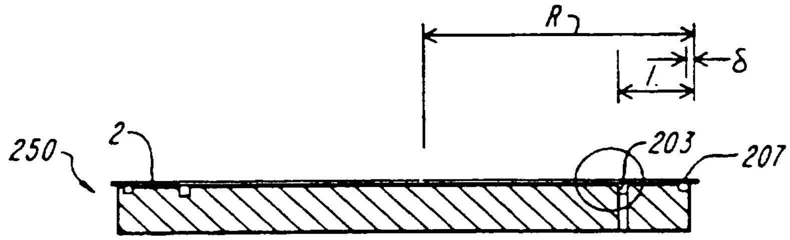


FIG. 8B

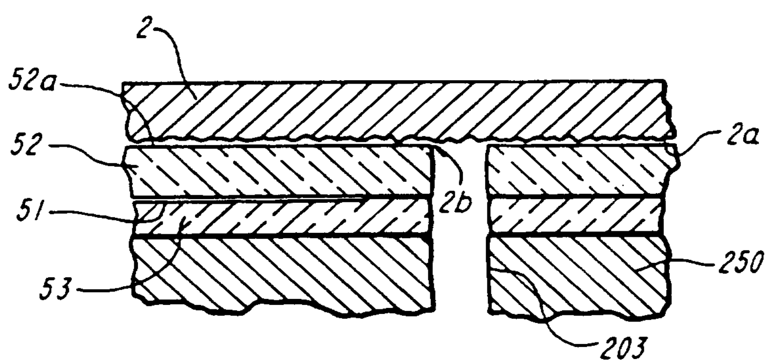


FIG. 8C

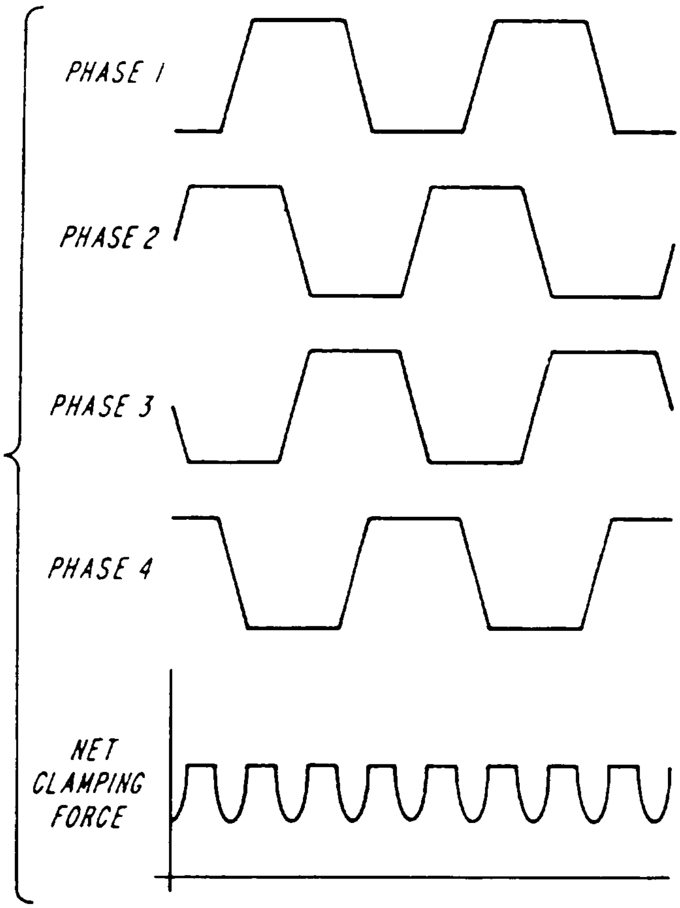

PHASE 1
PHASE 2
PHASE 3
PHASE 4
NET CLAMPING FORCE

FIG. 9

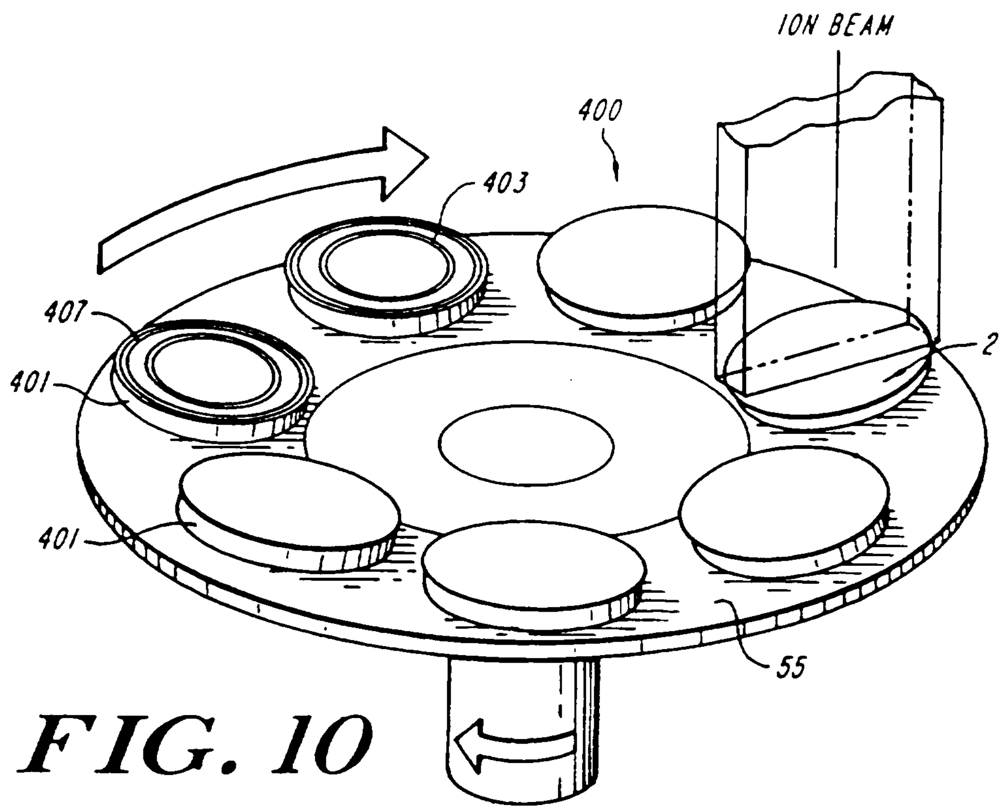

ION BEAM
400
403
407
401
2
401
55

FIG. 10

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATIO
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : **F28F 7/00, H01L 21/00** A3

(11) International Publication Number: **WO 96/13058**

(43) International Publication Date: 2 May 1996 (02.05.96)

(21) International Application Number: PCT/US95/13158

(22) International Filing Date: 17 October 1995 (17.10.95)

(30) Priority Data: 08/323,764 17 October 1994 (17.10.94) US

(71) Applicant: DIAMOND SEMICONDUCTOR GROUP, INC. [US/US]; 14 Blackburn Center, Gloucester, MA 01930 (US).

(72) Inventor: WHITE, Nicholas, R.; 21 Friend Court, Wenham, MA 01984 (US).

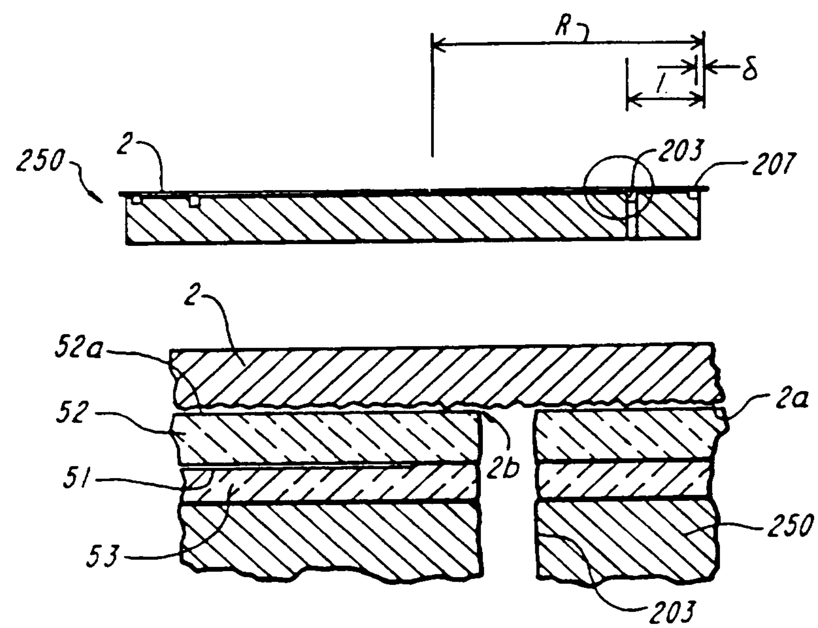
(74) Agents: LAHIVE, John, A., Jr. et al.; Lahive & Cockfield, 60 State Street, Boston, MA 02109 (US).

(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(88) Date of publication of the international search report: 27 June 1996 (27.06.96)

(54) Title: APPARATUS AND METHOD FOR TEMPERATURE CONTROL OF WORKPIECES IN VACUUM



(57) Abstract

A flat workpiece (2) is placed in contact with a flat platen (201) in a vacuum chamber, and is held by a uniformly-distributed force while a small mass flow of gas is introduced along a contour (203) to form a uniform pressure region between the flat workpiece (201) and the platen (2). Separation of the two surfaces due to surface roughness is less than the gas mean free path, and high rates of heat transfer are obtained uniformly over the area of the workpiece (2). A scavenging port (207), located outwardly of the gas introduction contour (203) is differentially pumped to reduce the rate of gas leakage into the chamber. Pressure is provided by an electrostatic clamp (250) where the voltage activation sequence prevents workpiece vibration. A clamping current sensor immediately detects degree of contact, e.g. due to debris on the platen, and initiates a suitable warning or control.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgystan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo			SE	Sweden
CH	Switzerland	KR	Republic of Korea	SI	Slovenia
CI	Côte d'Ivoire	KZ	Kazakhstan	SK	Slovakia
CM	Cameroon	LI	Liechtenstein	SN	Senegal
CN	China	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
CZ	Czech Republic	LV	Latvia	TJ	Tajikistan
DE	Germany	MC	Monaco	TT	Trinidad and Tobago
DK	Denmark	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	US	United States of America
FI	Finland	ML	Mali	UZ	Uzbekistan
FR	France	MN	Mongolia	VN	Viet Nam
GA	Gabon				

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/13158

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : F28F 7/00; H01L 21/00
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 165/80.1-80.5, 185; 29/25.01, 25.02/ 34/239; 118/59, 724, 725, 728; 269/ 8, 21, 903; 279/128; 361/243; 437/248

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US, A, 4,603,466 (MORLEY) 05 AUGUST 1986, see entire document.	1, 3, 10-11, 18-20 ---- 2, 4-5
Y	US, A, 5,179,498 (HONGOH ET AL) 12 JANUARY 1993, column 6, lines 31-35.	4-9, 15-17, 21-24
Y	US, A, 5,184,398 (MOSLEHI) 09 FEBRUARY 1993, see Figures 4b and 8.	4-9, 15-17, 21-24
Y	US, A, 5,345,999 (HOSOKAWA) 13 SEPTEMBER 1994, column 4, lines 32-36 and Figure 4.	4-9, 15-17, 21-24

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 FEBRUARY 1996	23 APR 1996

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	LEONARD R. LEO
Facsimile No. (703) 305-3230	Telephone No. (703) 308-2611

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	US, A, 5,460,684 (SAEKI ET AL) 24 OCTOBER 1995, see Abstract and Figures 1-2.	1-2, 10, 12, 18, 20
Y, P		3-9, 11, 13-17, 19, 21-24
Y	EP, A, 460 955 (FRITIGER) 11 DECEMBER 1991, see page 8, column 2, lines 27-30.	4-9, 15-17, 21-24
A	US, A, 5,103,367 (HORWITZ ET AL) 07 APRIL 1992, see column 2, lines 49-53.	21-24
A	JP, A, 3-227,554 (IIMURO) 08 OCTOBER 1991, see Abstract.	1-14, 18-20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/13158

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

165/80.2, 185; 118/728; 269/8, 21, 903; 279/128; 361/234; 437/248